Investment Analysis Report
En Route
Controller-Pilot Data Link Communications (CPDLC) Build I and IA

Mission Need Statement # 042
December 24, 1998

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CPDLC Build I/IA Investment Analysis Report

Executive Summary

The Federal Aviation Administration's (FAA) Associate Administrator for Research and Acquisition (ARA-1), on behalf of the program sponsors, the Associate Administrators for Air Traffic Services (AAT-1) and Airway Facilities Services (AAF-1), requested an investment analysis for the En Route Controller-Pilot Data Link Communications (CPDLC) Build I and IA program. The Investment Analysis & Operations Research Directorate (ASD-400) formed a team to conduct an analysis of the candidate architecture for implementing the program, as recommended by the Data Link Path Team, a joint FAA/Industry/User working group chaired by Jack Loewenstein, AND-700. This team was a sub-group of the NAS Modernization Task Force Data Link Team, chaired by John Kern of Northwest Airlines. The NAS Modernization Task Force Data Link Team is an advisory group to the FAA Administrator on the future of data link. The objective of the Investment Analysis Team (IAT) was to analyze the recommended approach to support development of an Acquisition Program Baseline (APB), to be approved by the Joint Resources Council (JRC).

As stated in the Mission Need Statement (MNS) 042 for the Aeronautical Data Link System (ADLS) dated October 23, 1991, the FAA has established an operational plan for the Air Traffic Management (ATM) system of the twenty-first century. In order to realize the Communications, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) system, the National Airspace System (NAS) will rely increasingly on advanced capabilities provided by ground and airborne automation systems. This will require timely and accurate communication and management of information concerning flight, navigation, and surveillance data in all operational domains. In the future ATM environment it will no longer be possible to rely exclusively on voice messages for the exchange of information. The transition from voice for pilot-controller communications to a mixture of voice and data communications is a key goal for Air Traffic Control (ATC).

The CPDLC program initiative is a first installment of the future full NAS-Wide Data Link. This document focuses on data communications service requirements for the En Route CPDLC portion of the Operational Requirements for the ADLS document (dated January 3, 1995) prepared by the Data Link Operational Requirements Team (DLORT). CPDLC Build I and IA will provide en route air traffic operations an initial set of operational messages that allows the NAS community to utilize data link functionality over the continental United States.

The goal of the CPDLC project is to provide a means of data communications in ATC operations that will supplement air/ground voice communications. This addition of data communications will support improvements in airspace use and capacity. Data communications will:

- Provide for a more dynamic and efficient air/ground information exchange mechanism.
- Provide an additional means of communication between pilots and controllers.
- Reduce congestion on the voice channels.
- Reduce operational errors resulting from misunderstood instructions and read back errors.

Implementation of CPDLC will be evolutionary, facilitating early delivery of user benefits and providing an orderly transition to the use of more advanced concepts and equipment in the future NAS Architecture.

The CPDLC architectures are based on current technologies being used or proposed in the marketplace. These notional architectures were included in a Request for Information (RFI) published to solicit industry comments and invite suggestions for innovative solutions. The team relied on RFI responses, other analysis and engineering judgment to evaluate the recommended architecture.

Scope

A technical approach and acquisition strategy for implementing Aeronautical Data Link (ADL) was proposed by the Data Link Path Team. The Data Link Path Team divided the approach to satisfying the ADL mission need into the following six elements:

- Controller/Pilot Data Link Communications (CPDLC), En Route.
- Controller/Pilot Data Link Communications (CPDLC), Oceanic.
- (CPDLC Oceanic is not specifically addressed in MNS 042. It is addressed in the Ocean Automation Program, NPI 0048.)
- Controller/Pilot Data Link Communications (CPDLC), Terminal.
- Flight Information Service (FIS).
- Air Traffic Management (Decision Support Services).
- Tower Data Link System (TDLS).

The Data Link Path Team also recommended three phases for En Route CPDLC development and implementation. They are:

- CPDLC Build I will implement the messages required to perform Transfer of Communication (TOC), Initial Contact (IC), Altimeter Setting (AS), and an informational free text menu capability built by supervisory input and assigned to specified positions. These messages will be sent to data link-equipped aircraft using Aeronautical Radio, Inc.'s (ARINC) Very High Frequency Digital Link (VDL) Mode 2 air/ground communications subnetwork. VDL Mode 2 (or VDL-2) is an evolutionary step satisfying performance and reliability requirements for situations in which the message is not time-critical, and sufficient time is available for retransmission by voice or data if there is no confirmed receipt of the message. The plan calls for implementing this capability at one key site in June 2002.
- CPDLC Build IA will leverage the FAA's investment in the development of CPDLC Build I. CPDLC Build IA will increase the message set to accommodate assignment of speeds, headings, and altitudes as well as a route clearance function. A capability to handle pilot-initiated altitude requests will also be implemented. CPDLC Build IA will continue to use the VDL-2 air/ground communication subnetwork. The plan calls for implementing this capability at one key site in 2003 with national deployment completed by 2005.
- PDLC Build II will expand upon CPDLC Build IA services and messages. Build II will continue to operate over the VDL Mode 2 air/ground communication subnetwork but will evolve a subset of messages using standardized Aeronautical Telecommunication Network (ATN) protocols. These messages will be coordinated across adjoining International Civil Aviation Organization (ICAO) regions and will accommodate multi-part uplinks (e.g., crossings with time, speed, and altitude restrictions) and report instructions. The downlink capability for pilots to request clearances and respond to requests via CPDLC will be greatly enhanced. Airlines that participated in CPDLC Build I or IA should be able to participate in CPDLC Build II with few, if any, avionics changes. The schedule for implementing Build II has yet to be determined.
- CPDLC Build III is the final phase of the FAA's current ADL program. Details of the increased capabilities remain to be determined, but are likely to include additional messages

from the CPDLC message set (with selection of messages considering the lessons learned about benefits), Standards and Recommended Practices (SARPs)-compliant network management and security, and integration with Decision Support Services. The schedule for implementing Build III has yet to be determined.

The NAS Modernization Task Force Data Link Team endorsed the recommendations of the Data Link Path Team, and the Free Flight Select Committee and Steering Committee subsequently approved this phased approach. Widespread user support for the program and desire for an FAA commitment (for Data Link business case development) compelled the IAT to restrict the scope of the initial analysis to meet an October 30, 1998 JRC date. The Director, Investment Analysis Staff (ASD-400), was asked to develop a program baseline (and its associated APB documentation) for En Route CPDLC Build I and IA only. The analysis was essentially a baselining activity using Investment Analysis (IA) processes rather than an in-depth investment analysis that evaluated a variety of implementation alternatives. The analysis looked at Build II; however, that program is to be addressed on its own at an investment decision JRC planned for mid-1999. In addition, the analysis will be limited to the en-route environment only. Build III and terminal applications will not be addressed at this time.

Human Factors Considerations

Accurate and timely exchange of information is essential for effective air traffic management. Currently, radio/voice communication channels support the exchange of information in ATC. Data link is a set of technologies designed to communicate information between ground-to-air and ground-to-ground facilities air using digital information. Data Link is a system that is designed to supplement, not replace, the traditional radio/voice link between pilot and controller with the automated transfer and display of digital information. Providing visual rather than voice information has the potential of reducing errors in speech perception (e.g., misunderstanding of clearances) and errors in working memory (i.e., forgetting).

Nevertheless, implementation of data link systems has a number of generic human factors implications. First, at the interface, a data link system generally relies on keyboard interactions to compose messages. Keyboard composition can be both cumbersome and prone to error. Data link also has the potential to provide more accurate although slightly slower communications. Slower communications can be significant because longer delays reduce communication efficiency. Second, data link relies on a visual-manual interface both on the ground and in the air. This shift from a radio/voice interface to a visual-manual interface has potential workload implications. For both the pilot and controller, data link may also increase "heads-down time", diverting visual attention from ongoing flight or ATC tasks that are themselves mostly visual-manual. Third, data link reduces both the need for human speech and the reliance on speech for controller-pilot communication. In principle, time is saved, although not always in practice. Pilots and controllers also glean useful party-line information when overhearing messages between controllers and other pilots on the same frequency. Finally, and perhaps more profound, data link has the potential to make available to both controller and pilot digital information from automated agents at either location, of which one or the other human participant may be unaware. It is important to consider the implications of all of these human factors issues in the investment analysis process as a means to reach an informed acquisition decision.

Executive Summary

Major Assumptions, Constraints, and Conditions

Several assumptions, constraints, and conditions guided the investment analysis initially. They are described below.

- Accept the data link implementation strategy as defined by the Data Link Path Team as the point of departure in the investment analysis and any excursions.
- The CPDLC will use existing inter-facility communications for interfaces to ARINC or to other centers. The APB includes funding for additional capacity should it be required. (Current FAA National Airspace Data Interchange Network II (NADIN II)/ARINC gateway interfaces may not handle the additional CPDLC message load. It is not known what future plans AOP-400 may have for upgrading the existing NADIN II/ARINC interfaces. Existing circuit data rates may have to be increased or new links installed).
- The air-ground subnetwork for Build I and IA will be contracted to a service provider, but inherently governmental functions such as ground system certification will be performed only by the FAA.
- Leverage Build I/Aircraft Communications Addressing and Reporting System (ACARS) software development, Operational Test and Evaluation (OT&E) and automation integration activities, and Preliminary Eurocontrol Test of Air/ground Data Link (PETAL) trials.
- Each Build I is constrained by Host software release schedule and Display System Replacement (DSR) implementation schedule.
- DSR/CPDLC prototype effort is required.
- Airlines are presumed to have equipped at least 100 aircraft by Initial Operational Capability (IOC), 200-400 aircraft by Final Operational Capability (FOC), and to have obtained certification approval. This assumption is based on the need for airlines to upgrade the avionics to support their Airline Operational Control (AOC) requirements using VDL-2, and on airline plans to participate in PETAL II.
- Assume no DSR software changes in Build I and IA (except for the DSR/CPDLC prototype effort mentioned above).
- Build IA is a software upgrade to Build I. Additional messages will be provided.
- Security for the communications link will be to the level defined in the current ICAO SARPs. Local security measures will comply with the requirements specified in the CPDLC Final Requirements Document (FRD) of October 28, 1998.

Economic Analysis

The economic analysis of the CPDLC Build I and IA programs was initially based on the implementation path recommended by the Data Link Path Team and endorsed by the NAS Modernization Task Force Data Link Team. However, early assessments of program affordability indicated that the recommended acquisition strategy was too ambitious for the funding available in the Capitol Improvement Plan (CIP) for FY99 and FY00. As a result, certain assumptions changed, four (4) alternative implementation schemes were considered, and cost estimates adjusted to achieve an affordable, executable, baseline program. The alternatives are shown in the table.

CPDLC Build I and IA Alternative Implementation Plans

Deployment	Option 1		Option 2		Option 3		Option 4	
Build I	6/02	Yes	6/02	Yes	6/02	No	6/02	No
Build IA	6/03	Yes	12/03	Yes	6/03	Yes	12/03	Yes

These alternative strategies required the IAT to revisit the cost estimate.

- Option 1 was the baseline program as originally planned. The cost estimate detailed in Appendix A was based on this program. Making adjustments to that estimate created the cost estimates for the other alternatives.
- Option 2 called for no changes to Build I but a six-month slip to Build IA implementation. The Build IA delay caused adjustments to software development costs and hardware/software integration costs with their corresponding funding requirements slipping one-year to the right.
- Option 3 resulted in a more extensive modification to the cost estimate, deleting all costs in Build I associated with national deployment. The estimate increased for Build IA (for the additional software development, hardware/software integration, and other support elements) to cover the national deployment of both Build I and Build IA message sets.
- Option 4 was the same as Option 3 plus a six-month delay in national deployment of Build IA.

Options 2 and 4 were eliminated from further analysis during the CPDLC Joint Resource Council (JRC) on October 30, 1998 when the user community advocated not to delay Build IA. Thus, the economic analysis was based on the adjusted costs of Options 1 and 3. Based on the CPDLC Build I and IA economic analysis and the risk assessment, the IAT recommended Option 3 as the Preferred Alternative.

The tables below illustrate Facilities and Engineering (F&E) and Operations and Maintenance (O&M) program costs by fiscal year (FY) for the Preferred Alternative in Constant and Then-year dollars, respectively.

Program Costs for CPDLC Build I/IA, Preferred Alternative (Constant FY98 $M)

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-15	Total
F&E	16.6	21.5	24.2	24.6	28.3	21.7	8.0	2.4					147.3
VDL-2 (F&E)				0.1	0.1	0.4	1.7	2.7	0.8				5.8
O&M						0.1	0.2	1.5	12.1	20.6	26.9	285.4	346.8
Total	16.6	21.5	24.2	27.7	28.4	22.2	9.9	6.6	12.9	20.6	26.9	285.4	499.9

Program Costs for CPDLC Build I/IA, Preferred Alternative (Then-year $M)

Build I	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-15	Total
F&E	15.4	13.2	12.4	7.8	2.9	0.5							**52.2**
Build IA	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10-15**	
F&E	1.5	9.2	13.3	18.9	28.6	24.1	9.3	2.8					**107.7**
Build I+IA	**99**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10-15**	
F&E(w/o VDL-2)	16.9	22.4	25.7	26.7	31.5	24.6	9.3	2.8					159.9
F&E/VDL-2				0.1	0.1	0.4	2.0	3.2	1.0	0.0			6.8
F&E Total	16.9	22.4	25.7	26.8	31.6	25.0	11.3	6.0	1.0	0.0	0.0	0.0	166.7
O&M	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	1.5	1.5	1.5	8.9	13.7
O&M /VDL-2							0.1	1.8	13.1	24.1	32.7	393.2	465.0
Total O&M						0.1	0.2	1.9	14.6	25.6	34.2	402.1	478.7
Total Program	16.9	22.4	25.7	26.8	31.6	25.1	11.5	7.9	15.6	25.6	34.2	402.1	**645.4**
Total VDL-2*	0.0	0.0	0.0	0.1	0.1	0.4	2.1	5.0	14.1	24.1	32.7	393.2	**471.8**

*/ These VDL-2 costs reflect FAA plans to pay for uplink and downlink message costs

Net Present Value and Benefit/Cost Ratio

The two economic measures that are generally referenced when making an investment decision are Net Present Value (NPV) and Benefit/Cost (B/C) Ratio. The table below summarizes the results of the CPDLC economic analysis with and without the passenger value of time (PVT) estimate for both the Build I and IA Preferred Alternative.

Range of Estimates at the 20/80% and 80/20% Confidence Levels ($M)

CPDLC Builds I and I and IA, Preferred Alternative	Without PVT		With PVT	
	Range	Most Likely	Range	Most Likely
Present Value Costs	274-336	288	274-336	288
Present Value Benefits	259-342	313	475-629	576
Net Present Value	(56)-47	26	166-326	288
Benefit-Cost Ratio	0.8-1.2	1.1	1.5-2.1	2.0

Affordability Assessment

FY98 funding supported development of a different architecture for this program. Since that approach is not being pursed, the FY98 funding in the following table is not considered part of the CPDLC Builds I and IA APB. A separate segment will be created in the CIP for that previous work. As illustrated in the table, the funding for CPDLC exceeds the levels provided in the CIP.

Affordability Assessment for CPDLC (Then-year $M)

	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04 & beyond	Total
CIP 10/2/98	10.4	15.7	12.3	12.4	12.9	15.8	87.8	156.9
APB	0	16.9	22.4	25.7	26.7	31.5	40.5	163.7
Delta		-1.2	-10.1	-13.3	-13.8	-15.7	47.3	-6.8

The Systems Engineering/Operational Analysis Team (SEOAT) has determined that lower priority programs must be reduced to fund CPDLC. The SEOAT will determine which programs are to be reduced for FY 2000 when preparing the reclama to the FY 2000 Office of Management and Budget (OMB) passback. Years 2001 and beyond will be addressed in the FY 2001 formulation process. The delta in FY 1999 will be absorbed with the SETA line.

Risk Assessment

The IAT reviewed all areas of the investment analysis to identify risks that could affect the success of the program, and identify means for mitigating those risks. The risk assessment group collaborated with other groups within the IAT to mitigate risks during the investment analysis phase wherever possible, and to refine the descriptions of risk and its mitigation when risk could not be mitigated at this stage of the project life cycle. The potential impact of each risk was considered from the perspectives of cost, schedule, technical, and user acceptance; the likely magnitude and probability of each risk were also assessed.

The major categories of risk addressed are:

- Software development
- System integration
- User equipage
- Test and evaluation
- Security
- Operation and maintenance
- Transition.

Recommendations

- Reaffirm the need for the CPDLC program initiative.
- Affirm the segmentation "Build" approach to the CPDLC program.
- Affirm the recommendation for VDL-Mode 2 as the preferred alternative for CPDLC Build I and IA.
- Approve the Investment Decision for CPDLC Build I and IA.
- Approve the proposed CPDLC APB for Build I and IA.
- Assign the CPDLC program to AND-700 for implementation.
- Assign responsibility for determining FAA policy for payment of VDL-2 communications service provider costs.

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CPDLC Build I/IA Investment Analysis Report

1. Introduction

This report documents activities conducted by the Controller-Pilot Data Link Communications (CPDLC) Investment Analysis Team (IAT) that led to the development of the Investment Analysis Report (IAR) and Acquisition Program Baseline (APB). As specified in the Acquisition Management System (AMS) and the Investment Analysis Process Guidelines, the report summarizes the mission need, requirements, costs, benefits, schedules, alternatives, assumptions, and risks. The report also documents the economic assessment, and the results of the affordability assessment conducted by the System Engineering Operational Analysis Team (SEOAT). Finally, it summarizes the IAT's Investment Decision recommendation to the Joint Resource Council (JRC) for providing a controller-pilot data link capability in the National Airspace System (NAS), and it identifies the next steps.

1.1. Background

As stated in the Mission Need Statement (MNS) 042 for the Aeronautical Data Link System (ADLS) dated April 23, 1991, the Federal Aviation Administration (FAA) has established an operational plan for the Air Traffic Management (ATM) system of the twenty-first century. In order to realize the Communications, Navigation, and Surveillance (CNS)/ATM system, the NAS will rely increasingly on advanced capabilities provided by ground and airborne automation systems. This will require timely and accurate communications and management of information concerning flight, navigation, and surveillance data in all operational domains. In the future ATM environment it will no longer be possible to rely exclusively on voice messages for the exchange of information. The transition from voice for pilot-controller communications to a mixture of voice and data communications is a key goal for the future Air Traffic Control (ATC) system.

This document focuses on data communications service requirements for the CPDLC portion of the Operational Requirements for the ADLS document dated January 3, 1995 prepared by the Data Link Operational Requirements Team (DLORT). A Final Requirements Document (FRD) was approved on October 28, 1998. The initial implementation of CPDLC includes en route air traffic operations with planned evolutionary transition to the terminal and flight service environment.

The goal of the CPDLC project is to provide a means of data communications in ATC operations that will supplement air/ground voice radio communications. This addition of data communications will support improvements in airspace use and capacity. Data communications will:

- Provide for a more dynamic and efficient air/ground information exchange mechanism
- Provide an additional means of communication between pilots and controllers
- Reduce congestion on the voice channels
- Reduce operational errors resulting from misunderstood instructions and readback errors

Implementation of CPDLC will be evolutionary, facilitating early delivery of user benefits and providing an orderly transition to the use of more advanced concepts and equipment in the future NAS Architecture.

1.2. Scope

The scope of this effort was to conduct an analysis of the candidate architecture for implementing the program, as recommended by the Data Link Path Team, a joint FAA/Industry

/User working group chaired by Jack Loewenstein, AND-700. This team was a sub-group of the NAS Modernization Task Force Data Link Team, chaired by John Kern of Northwest Airlines. The NAS Modernization Task Force Data Link Team is an advisory group to the FAA Administrator on the future of data link. The Data Link Path Team divided the approach to satisfying the Aeronautical Data Link (ADL) mission need into the following six elements.

- Controller/Pilot Data Link Communications, En Route.
- Controller/Pilot Data Link Communications, Oceanic (CPDLC Oceanic is not specifically addressed in MNS 042. It is addressed in the Ocean Automation Program, NPI 0048).
- Controller/Pilot Data Link Communications, Terminal.
- Flight Information Service (FIS).
- Air Traffic Management (Decision Support Services).
- Tower Data Link System (TDLS).

The Data Link Path Team also recommended three phases for En Route CPDLC development and implementation. The CPDLC En Route Builds are described in Section 1.3 below.

The NAS Modernization Task Force Data Link Team endorsed the recommendation of the Data Link Path Team, and the Free Flight Select Committee and Steering Committee subsequently approved this phased approach. Widespread user support for the program and desire for an FAA commitment (for Data Link business case development) compelled the IAT to restrict the scope of the initial analysis to meet an October 30, 1998 JRC date. The Director, Investment Analysis Staff (ASD-400), was asked to develop a program baseline (and its associated APB documentation) for En Route CPDLC Build I and IA only.

This analysis is essentially a baselining activity using Investment Analysis (IA) processes rather than an in-depth investment analysis that evaluates a variety of implementation alternatives. The analysis looked at Build II; however, that program is to be addressed on its own at an investment decision JRC planned for mid-1999. Build III and terminal applications are also not addressed at this time.

1.3. En Route CPDLC Development Approach

The phases for En Route CPDLC development and implementation recommended by the Data Link Path Team are:

1.3.1. CPDLC Build I

CPDLC Build I will implement the messages required to perform Transfer of Communication (TOC), Initial Contact (IC), Altimeter Setting (AS), and an informational free text menu capability built by supervisory input and assigned to specified ground controller positions. These messages will be sent to data link-equipped aircraft using Aeronautical Radio, Inc.'s (ARINC) Very High Frequency Digital Link (VDL) Mode 2 air/ground communications subnetwork. VDL Mode 2 (or VDL-2) is an evolutionary step satisfying performance and reliability requirements for situations in which the message is not time-critical, and sufficient time is available for retransmission by voice or data if there is no confirmed receipt of the message. The plan calls for implementing this capability at one key site in 2002 with national deployment deferred until Build IA.

1.3.2. CPDLC Build IA

CPDLC Build IA will leverage the FAA's investment in the development of CPDLC Build I. CPDLC Build IA will increase the message set to accommodate assignment of speeds, headings, and altitudes as well as a route clearance function. A capability to handle pilot-initiated altitude requests will also be implemented. CPDLC Build IA will continue to use the VDL-2 air/ground communication subnetwork. The plan calls for implementing this capability at one key site in 2003 with national deployment completed by 2005.

1.3.3. CPDLC Build II

CPDLC Build II will expand upon CPDLC Build IA services and messages. Build II will continue to use the VDL-2 air/ground communication subnetwork. An additional subset of messages will be coordinated across adjoining International Civil Aviation Organization (ICAO) regions and will accommodate multi-part uplinks (e.g., crossings with time, speed, and altitude restrictions) and report instructions. The downlink capability for pilots to request clearances and respond to requests via CPDLC will be greatly enhanced. Airlines that participated in CPDLC Build I or IA should be able to participate in CPDLC Build II with few, if any, avionics changes. The schedule for implementing Build II has yet to be determined.

1.3.4. CPDLC Build III

The deployment of CPDLC Build III is the final phase of the FAA's current ADL program. Details of the increased capabilities remain to be determined, but are likely to include additional messages from the CPDLC message set (with a selection of messages considering the lessons learned about benefits), Standards and Recommended Practices (SARPs)-compliant network management and security, and integration with Decision Support Services. The schedule for implementing Build III has yet to be determined.

1.4. Major Assumptions, Constraints, and Conditions

Several assumptions, constraints, and conditions guided the investment analysis initially. They are described below.

- Accept the data link implementation strategy as defined by the Data Link Path Team as the point of departure in the investment analysis and any excursions.
- Data to determine the current cost of existing systems resides with the Data Link Product Team (PT).
- The CPDLC will use existing inter-facility communications for interfaces to ARINC or to other centers and any additional National Airspace Data Interchange Network (NADIN) capacity will be included in the APB. (Current FAA NADIN II/ARINC gateway interfaces may not handle the additional CPDLC message load. It is not known what future plans AOP-400 may have for upgrading the existing NADIN II/ARINC interfaces. Existing circuit data rates may have to be increased or new links installed).
- The transition costs from Build I to IA will reflect the cost estimate of site surveys, Operational Test and Evaluation (OT&E), site preparation, facility modifications, infra-structure replacement, and service cut-over.
- The air-ground subnetwork for Build I and IA will be contracted to a service provider, but inherently governmental functions such as ground system certification will be performed only by the FAA.

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- A fifteen-year life cycle will be assumed for generating the APB.
- Leverage Build I/Aircraft Communications Addressing and Reporting System (ACARS) software development, OT&E and automation integration activities for Preliminary Eurocontrol Test of Air/ground Data Link (PETAL) trials.
- Each CPDLC Build I is constrained by the Host software release schedule and Display System Replacement (DSR) implementation schedule. A Host software release is required for each build.
- DSR/CPDLC prototype effort is required.
- Airlines are presumed to have equipped at least 100 aircraft by Initial Operational Capability (IOC), 200-400 aircraft by Final Operational Capability (FOC), and to have obtained certification approval. This assumption is based on the need for airlines to upgrade the avionics to support their Airline Operational Control (AOC) requirements using VDL-2, and on airline plans to participate in PETAL, Phase I and Phase II (PETAL II).
- Requirements for recording uplinks and downlinks on aircraft will be deferred until Build II, at which time all communications between controllers and pilots will be subject to the same recording requirements as for voice.
- Assume no DSR software changes in Build I and IA.
- Build IA is a software upgrade to Build I. Additional messages will be provided.
- Security for the communications link will be in accordance with the approved ICAO SARPs. Local security measures will comply with the requirements specified in the CPDLC FRD of October 28, 1998.

2. Mission Need, Benefits, and Requirements

2.1. Mission Need

As stated in the Mission Need Statement (MNS) 042 for the ADLS (Aeronautical Data Link System) dated April 23, 1991, the FAA has established an operational plan for the ATM system of the twenty-first century. In order to realize the CNS/ATM system, the NAS will rely increasingly on advanced capabilities provided by ground and airborne automation systems. This will require timely and accurate communication and management of information concerning flight, navigation, and surveillance data in all operational domains. In the future ATM environment it will no longer be possible to rely exclusively on voice messages for the exchange of information. Transition from voice for pilot-controller communications to a mixture of voice and data communications has been identified as a key goal for ATC. The ADLS MNS 042 was revalidated on May 20, 1998.

2.2. Benefits

2.2.1. Overview

The benefits of Data Link have been articulated in the reports of several data link studies. A few of these reports and studies and their conclusions are shown below.

- Chew, Captain Russell, American Airlines, *ATC Data Link Roadmap*, NAS Modernization Task Force, Data Link Sub-Group, May 21, 1998.
    - Concluded that the FAA Program must have a comprehensive roadmap, must maximize use of limited resources to improve schedule, and should use the Eurocontrol data link efforts to enhance FAA Data Link program definition, schedule, and success.
    - Benefits discussion is limited to Economics Validation with a Deterministic Cost Benefit Analysis (CBA). Possible benefits identified are improved capacity from reduced controller workload. Costs should be identified for airlines, network, and ATC.
    - PETAL can help to validate the economic benefits but no data is provided. PETAL-I conclusions identified the most useful messages as Direct Route (clearance), Frequency Change (instruction), Aircrew Acknowledgement, and Microphone Check (instruction), Aircrew Information (manual downlink), and Flight Level (clearance). "Data link appears useful for communication in strategic situations. It does not appear useful for tactical aircraft separation regardless of delivery."
- *Data Link Benefits Study Team, User Benefits of Two-way Data Link ATC Communications: Aircraft Delay and flight Efficiency in Congested En Route Airspace* (Report identifier DOT/FAA/CT-95/4), FAA Technical Center February 1995.
    - The report demonstrated that controllers using two-way data link were able to provide ATC services that improved en route sector productivity and efficiency. The improvements included reduced aircraft ground delay, flight time, and flight distance in comparison to a current operational environment using only voice radio communications.
    - Reduced ground delays and flight times (demonstrated with data link) exceeded $8.6 million for the two sectors at the Atlanta Air Route Traffic Control Center (ARTCC).

- Estimates for savings nationwide were $337 million in operating costs annually with the introduction of two-way data link ATC communications.

- An Inventory of Cost Benefit Studies in the Field of ATC Data Communications, Prepared for the Directorate of EATCHIP[1] Development, EUROCONTROL, Management in Confidence.

  Evaluated previous benefit studies, and identified: (1) the ten most useful benefit studies for further reference; and (2) the following benefit categories:

  - Operational Efficiency including;
    - Improved routing, such as flexible or random routing
    - Optimum altitude
    - Optimum Speed
    - Improved use of airspace
    - Improved communications
    - Improved access to flight information
  - Capacity
    - Improved Approach and Take off Capability
    - Reduced Ceiling/ Visibility Restriction
    - Reduced Flow Restrictions
    - Improved Surface Surveillance and Control
  - Safety
    - Flight Information Services
    - Improved Situation Awareness
    - Reduction of Miscommunication

In addition, the FAA Technical Center is currently conducting studies on improving controller productivity using the modeling and simulation tool SIMulation MODel Development and Validation or SIMMOD.

2.2.2. Benefits Methodology

According to the 1997 Aviation Capacity Enhancement Plan, the average delay by phase of flight in 1996 is 15 minutes, measured by Airline Service Quality Performance (ASQP) data. This is described as 7.5 minutes of delay per operation (where a flight has two operations, take-off and landing), with 26.6 million operations at the top 100 airports in the NAS. This computes to 199.5 million minutes of delay. Of these, 4.4 minutes per flight or 58.5M minutes are categorized as delays within the airborne phase. Further, taxi-out and gate-hold delays together average 8.4 minutes per flight and total 112 million minutes of delay per year.

The 1995 FAA data link benefits study (alluded to in paragraph 2.2.1), also known as the Atlanta study, examined two sectors of airspace surrounding the Atlanta Terminal Radar Approach Control Facility (TRACON). One sector focused on delays caused by capacity problems in a high altitude en route departure sector. The other examined saturation situations leading to inefficient processing of aircraft arrivals. Both experiments applied a case study approach to a current constraint: the time necessary to transmit voice messages is limit to the number of

[1] European Air Traffic Control Harmonization and Integration Program

aircraft in a sector. The complexity of desired routing, as well as sheer number of aircraft are also limits, although the easing of one constraint can lead to the acceptance of a higher buffer in another.

With this backdrop, the Atlanta experiment indicated a reduction of en route sector (airborne) delays of 6.9 million minutes per year and ground delays of 4.6 million minutes per year. This time reduction provides a corresponding reduction of $337M in aircraft direct operating costs (ADOC).

The Atlanta study is generally acknowledged as the only quantitative study to date for data link benefits in en route airspace. For use with the CPDLC Build IA, the study was updated and criticized flaws were addressed. Finally, maximum and minimum values were placed on variables to account for uncertainty and to develop a "high confidence" benefit estimate. Detailed methodology is discussed in Section 6.2, Benefits.

2.3. CPDLC Requirements

CPDLC requirements were established based on mission need documented in MNS 042. These included considerations for:

- the operations concept for both the Air Traffic service provider and the user,
- performance requirements in terms of compliance with standards, and operational, functional, and technical performance,
- the physical and functional integration of the capability into the NAS, including human factors impacts, and
- implementation and in-service support.

Below is a summary of some of the key, high-level system requirements. For a detailed requirements description refer to the *Requirements Document for En Route Controller-Pilot Data Link Communications (CPDLC) Service*, approved October 28, 1998.

- CPDLC service will be available at all 20 domestic ARTCC facilities, the William J. Hughes Technical Center and the Mike Monroney Aeronautical Center.
- The CPDLC ground system shall be capable of providing CPDLC service to a minimum of 400 aircraft, per facility, at any given time, as defined in *Data Link Operational Requirements Document*, section 4.6, Table 4-9, stage 2.
- CPDLC system shall provide the following level of end-to-end transfer delay performance within any continuous one hour period:
    - **Domain -** En Route
    - **Mean End-to-End Transfer Delay -** ≤10 sec
    - **95% End-to-End Transfer Delay -** ≤15 sec
    - **99.996% End-to-End Transfer Delay -** ≤22 sec
- The CPDLC System shall comply with ICAO SARPs, *Aeronautical Telecommunication Network (ATN), Volume II, part II,* Communications Procedures, Chapter 5, Aeronautical Mobile Service.
- The FAA CPDLC Ground System shall archive all CPDLC messages in accordance with FAA Order 7210.3, *Facility Operations and Administration*.

- Only one sector shall be eligible to send data link messages to an aircraft at any given time, within the ATC facility with CPDLC eligibility. The FAA CPDLC Ground System shall provide for transfer of CPDLC eligibility between ATC sector control positions.
- The FAA CPDLC Ground System shall indicate to the controller when messages are received out of order for a given link. The CPDLC System shall detect errors contained in received messages and notify end users of the type error that occurred.
- CPDLC service shall be classified essential as defined in NAS SR-1000, *FAA NAS System Requirements Document*.
- CPDLC System data integrity shall be 10^{-6} or better.
- CPDLC unique ground equipment shall have a Mean Time Between Failure (MTBF) equal to or greater than 26,280 operational hours.
- CPDLC unique ground equipment Mean Time To Repair (MTTR), as defined by FAA Order 6040.15, *National Airspace Performance Reporting System*, par. 702f, shall be no more than 0.5 hours. Availability
- Communications service availability provided by the CPDLC service in accordance with *National Airspace Performance Reporting System*, par. 702c, shall be 0.999 or greater on an individual sector basis, in accordance with - NAS-SS-1000, FAA NAS System Specification, Volume I, par. 3.2.1.2.8.1g.
- CPDLC unique ground equipment shall have an inherent availability of 0.999 or greater.
- It is not possible to identify radio spectrum within the air traffic control channels in the 118-137 MHz band to accommodate CPDLC service. Implementation of Build I and IA will necessarily be by service provider using properly allocated radio spectrum protected for aeronautical safety services.
- Human factors application shall consider the system operator (air traffic control specialist staffing an en route operational position) and the system maintainer.
- Human factors issues are critical to safety, availability, and the effectiveness of the CPDLC service. Early human-in-the-loop prototyping of the human interfaces shall be accomplished prior to major design commitments.

3. Alternatives Analysis

3.1. Background

In order to understand and appreciate the CPDLC Build I and IA Alternatives Analysis process, it is necessary to be aware of several related ADL activities.

A CPDLC Build I program existed at the time the need for an ADL IA was identified. The program was a development of hardware and software to allow controller pilot data link communications in a demonstration environment. The demonstration was to use selected messages that were compatible with ARINC's current ACARS character oriented air-ground communications subnetwork. Four messages were to be sent from the FAA Host computer at the Minneapolis center to ACARS equipped Northwest Airlines aircraft. Current installed avionics would have required only a minor software upgrade to accept, display, and respond to these new messages. CPDLC Build I (ACARS) was an element of the Free Flight Phase One program.

In the fall of 1997 the Free Flight Steering Committee NAS Modernization Task Force established a Data Link Team, led by John Kern of Northwest Airlines and comprised leaders from industry and the FAA. The goal of the group was to come to a clear understanding of the data link program, and to identify a roadmap for implementation and use of ADL.

In the spring of 1998, based on a request from Air Traffic Systems Requirements (ARS) to Systems Architecture and Investment Analysis (ASD), an investment analysis effort was initiated for ADL. A preliminary meeting was held to identify the scope of the ADL IA. It was determined that the IA should address CPDLC. In fact, because CPDLC Build I (ACARS) was already a well-defined part of Free Flight Phase One, the IA would address CPDLC Builds beyond the use of ACARS. IATs were formed to study the specific areas of requirements, assumptions, architecture alternatives, and APB.

At one of the Data Link Team meetings in the summer of 1998, participants learned that American Airlines planned to participate in the Preliminary Eurocontrol Test of Air/ground Data Link, Phase I and II (PETAL II) trials in Europe. American intends to equip at least four aircraft with Aeronautical Telecommunication Network (ATN) compliant very high frequency (VHF) Digital Link Mode 2 (VDL-2) radios and ATN compliant CPDLC functionality for these trials.

With this new opportunity of an applicant proposing VDL-2, the roadmap of the ADL program became unclear. A subgroup of members from the Data Link Team, the Data Link Path Team, was formed to identify a near and mid term path for the United States En Route CPDLC program by July 1, 1998. The path would be presented to, and evaluated by, the Data Link Team for "advancement up the chain" through the RTCA Free Flight Select and Steering Committees.

Two groups undertook concurrent efforts to define alternatives for the CPDLC program. The first, the Data Link Path Team, worked to identify which near and mid term subnetworks and message sets should be used to provide CPDLC. The second, the FAA Investment Analysis Architecture Alternatives Team, identified CPDLC program assumptions and candidate architectures for the IA.

The focus of the Data Link Path Team was programmatic in nature. The group essentially identified the following two potential courses of action: (1) continue with the current program (CPDLC over ACARS at the Minneapolis Center); or (2) develop an evolutionary program (CPDLC over VDL-2 with American Airlines as launch airline and certification applicant). The second course would retain the same controller interface and set of four messages but use standardized ATN protocols and operate over ARINC's new VDL-2 digital network instead of the ACARS analog network.

The focus of the Architecture Alternatives Team was technical in nature. The group worked to describe potential variations in a CPDLC system architecture based on assessment of the interface with the NAS Data Link Applications Processor (DLAP) and the Host Interface Display (HID)/NAS/Local Area Network (LAN) elements. To validate the team's primary assumption that the architecture of the subnetwork would be ARINC's VDL-2 network, a Request for Information (RFI) was sent to industry inviting concepts for a communication subnetwork service which could meet the requirements of the internationally agreed upon ATN.

3.2. Assumptions and Constraints

The alternatives analysis was initially based on the following list of technical assumptions and constraints.

3.2.1. Constraints

In order to achieve global interoperability, the solution must be compliant with the ICAO Manual of Technical Provisions for the Aeronautical Telecommunication Network (ICAO 9705-AN/956), which specifies the message sets and communication protocols to be used for CPDLC.

- IOC is required by 2002.
- No FAA VHF frequencies are available for data link communications.

3.2.2. Assumptions

- ATN compliance does not require implementation of the entire CPDLC message set, as long as the handling of unimplemented messages complies with the ATN SARPs.
- Several U.S.-based and international airlines are planning to equip aircraft with ATN-compatible avionics for participation in PETAL II.
- The FAA implementation of CPDLC will use a subset of the message set that is consistent with the PETAL II message set to minimize airline investment.
- The message subset implemented in the avionics is expected to include all messages necessary for implementation of CPDLC Build I and IA.
- CPDLC Build I and IA will be used only for non-time critical situations.
- CPDLC Build I and IA will be essential services (as opposed to critical) with corresponding service availability and service restoral times.
- Many airlines are currently planning to upgrade their fleets to VDL-2 avionics for AOC functions (Digital ACARS).
- A criterion for Free-Flight Phase One includes development of CPDLC software for evaluation. This software will serve as the basis for national deployment of CPDLC Build I and Build IA.
- ATN compatible VDL-2 network coverage of en route is required by 2001.
- ATN router work will be completed by 2000.

3.3. Candidate Summary

Candidates were developed via three efforts: work by the Architecture Alternatives Team, work by the Data Link Path Team, and review of RFI responses.

The candidate considered in this IA consists of the architecture described in paragraph 3.3.1 below, and the implementation builds described in paragraph 3.3.2 below.

3.3.1. Architecture Alternatives Team

The Architecture Alternatives Team first developed the assumptions and constraints governing available options for CPDLC architectures. The team focused on variations in the elements (components or subsystems) of the CPDLC service architecture. The elements considered, with examples of each, are:

- **End Sytem --** DLAP
- **End System to Host Interface --** HID/NAS LAN
- **End System to Service Provider Interface --** Ground-Ground Router/NADIN Packet Switching Network
- **Air/Ground Subnetwork --** VDL-2

Analysis by the ATN and CPDLC experts on the Architecture Alternatives team yielded no alternatives that could meet the schedule for the elements defined in the above list. Essentially, there is only one candidate architecture for CPDLC en route implementation.

3.3.2. Data Link Path Team

The Data Link Path Team concentrated on programmatic and implementation alternatives. The primary consideration was whether or how the CPDLC program should implement and transition from ACARS to VDL and which CPDLC messages should be implemented at what time.

The current CPDLC Build I will implement the messages required to perform TOC, IC, AS, and Pre-Defined Messages (PDM -- an informational free text menu capability built by supervisory input and assigned to specified positions). This set of four messages will use standardized ATN protocols and will be sent to data link-equipped aircraft using ARINC’s VDL-2 air/ground communications subnetwork. The use of VDL-2 is an evolutionary step satisfying performance and reliability requirements for situations in which the message is not time-critical, and sufficient time is available for retransmission by voice or data when there is no confirmed receipt of the message.

CPDLC Build IA will leverage the FAA’s investment in the development of CPDLC Build I. CPDLC Build IA will increase the message set to accommodate assignment of speeds, headings, and altitudes as well as a route clearance function. A capability to handle pilot-initiated altitude requests will also be implemented. CPDLC Build IA will continue to use the VDL-2 air/ground communication subnetwork.

3.3.3. Request for Information Responses

The RFI, sent out as part of the Architecture Alternatives effort, canvassed industry for ATN compatible subnetwork services. A critical assumption made by both the above teams was that VDL-2 was the only subnetwork meeting the requirements of ATN compatible CPDLC. The review of the responses to the RFI validated that assumption. The only subnetwork that could meet the FAA's ATN compatibility requirements (in the time frame defined in the CPDLC Final Requirements Document and Mission Need Statement revalidation) is VDL-2.

Seven companies responded to the RFI. Two companies have no intention to provide an air to ground subnetwork service. Of the remaining five, only three provided responses that could be assessed as having met the technical and operational requirements set forth in the RFI. Of the same five, only one company met the operational capability dates identified in the RFI. The results of the review indicate strongly that ARINC is the only service provider with frequencies under its management and infrastructure in place which would meet FAA planning requirements.

3.4. Evaluation

Because of the lack of serious candidates, other than that identified in the IA, there was no formal evaluation of alternatives.

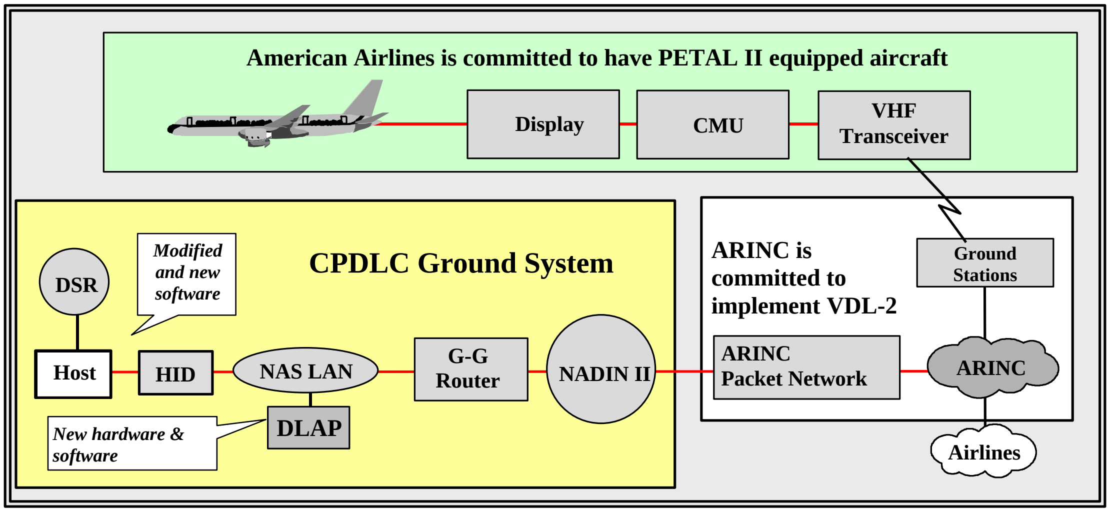

Figure 3-1 FAA Responsibilities and Industry Commitments

4. Human Factors Analysis

4.1. Background

Traffic delays resulting from communication bottlenecks are one of the primary factors that have driven the FAA's development of a two-way digital data link system for ATC communications. If implemented, the digital data link system will supplement the current radio/telephone communication channel by providing controllers with an alternate capability for sending clearances and other messages to aircraft operating within their sector. These messages will be discretely addressed to individual aircraft and presented on persistent (i.e. until erased) visual flight deck displays. In turn, aircrews will have the ability to downlink messages to the ATC controller. The messages proposed include standard clearances and instructions, pilot requests, weather information, Airport Terminal Information Services (ATIS) broadcasts, and free text messages.

Because data link is assumed to be a two-way channel, its description distinguishes between down-linked (air to ground) and uplinked (ground to air) messages. Correspondingly, the human factors issues will be somewhat different in the two environments. For example, in the cockpit, data link interface locations are alternatively proposed to reside in a separate console, embedded within the control and display unit of the flight management computer, or embedded in the multifunction display, an option chosen in the Boeing 777. On the ground, data link displays are positioned as windows on the DSR platform. In both cases, keyboard entry and graphic displays have been the standard approach, although alternative media are being considered.

Frequency congestion or competition for a single radio channel has led to substantial delays, as well as pilot frustration. One analysis suggested that airlines lost over $300,000,000 annually as a result of communications-induced delays (Federal Aviation Administration, 1995[1]). An equally strong rationale for the development of data link is concern over the vulnerability of standard radio communications to errors in speech perception and working memory. Furthermore, previous studies have indicated that 80 percent of information transfer problems occur on radio channels (Billings and Cheaney, 1981[2]). These factors have provided strong justification for seeking a controller-pilot data link communication system that can directly transfer information, ensuring that it is "permanently" (i.e., until erased) visible on a display in the form it was sent.

The FAA in 1988 initiated a data link research program, aggregating research that had been done prior to that time, initiating new research, and developing a program of airborne simulation and testing (Federal Aviation Administration, 1990[3]). The fundamental challenge for the FAA to satisfy the digital data link mission need is to develop a strategy that is both technically sound and cost effective.

The present strategy divides the program into six phases. They are:

1. CPDLC En Route.
2. CPDLC Oceanic. (CPDLC Oceanic is not specifically addressed in MNS 042. It is addressed in the Ocean Automation Program, NPI 0048.)
3. CPDLC Terminal.
4. FIS.
5. Air Traffic Management (Decision Support Services).
6. TDLS.

The first phase focuses on CPDLC in the en route environment (En Route CPDLC), which itself has been divided into four sub-phases or builds. The specific purpose of En Route CPDLC Build I is: (1) Understand the operational complexities, if any, associated with data linking a limited set routine messages; and (2) provide a baseline of operational knowledge as it relates to the digital transmission of TOC, IC, and AS messages and an informational free text menu capability. En Route CPDLC Build IA will continue to expand the types of message sets to include routine clearances as well as speed, heading, and altitude assignment messages. A capability to handle pilot-initiated altitude requests will also be included in this phase of development and testing. Further Builds will continue to expand the number of message sets and include different ATC domains such as Oceanic, Terminal, Flight Information Services, Air Traffic Management, and Terminal Data Link Service Replacement. In all phases or Builds, a critical aspect in the evolution of data link is the interaction between automated data link and the controller on the ground and automated data link and the pilot in the cockpit; namely, the human factors issues associated with data link technology.

4.2. Data Link Implementation Studies

Substantial efforts have been undertaken by both the FAA and by Eurocontrol (Program for Harmonized Air Traffic Management Research [PHARE][4], Preliminary Eurocontrol Test of Air/Ground Data Link, Phase I and II [PETAL II][5]) to ensure that data link can be implemented in a successful fashion. Recent studies by the FAA (1995[6], 1996[7]) and by Shingledecker and Darby[8] (1995) have evaluated the ground system in full mission simulations and corresponding efforts have evaluated the air side (FAA, 1996[9]; Lozito, McGann and Corker, 1993[10]; Gent and Van, 1995[11]). In all cases, overall measures of performance efficiency (e.g., controller productivity, sector capacity, communications access, service to airlines) have been collected and conjoined with more specific assessments of operator workload, opinion, pilot and controller response time, etc. The evaluation of data link has been generally favorable, although users have expressed qualifications about its appropriateness in some circumstances. Human-in-the-loop studies have revealed that a combined voice-data link system enables equal levels of flight efficiency with a reduced number of total communications (voice and data link), the latter reduction resulting in part because there are fewer requirements to repeat voice messages (Tolotta, 1992a[12], 1992b[13]).

The operational data have pointed to a number of guidelines for design as well as human factors issues. Those studies that have directly compared a data-link equipped aircraft with a radio-only aircraft have revealed benefits at various levels of air traffic management efficiency (e.g., increased traffic flow, reduced delays, FAA, 1995[14], 1996[15]).

There are flaws with these studies. It should be noted that the most detailed analysis of benefits have compared benefits in a data link simulation environment to those obtained using the same, but live, traffic scenario in the facility environment. That is, the latter baseline scenario was used to estimate the efficiency of radio-alone performance. In comparing data link conditions with radio-only conditions, there were differences not only in the communication mode (the interfaces) but also differences in traffic (simulated vs. live), in the controllers participating in the studies (on-the-job vs. the simulation study), and perhaps in the operating conditions. Worse yet, the most current assessment of data link benefits (Federal Aviation Administration, 1995[16]) compared data link communications only with data link plus radio communications in a simulated environment. There was no radio-only baseline (or control group) by which to measure the benefits (or lack of benefits) of data link communications. Furthermore, none of the studies described above collected baseline measures of workload, which could be compared with the data link condition measures.

Accordingly, there are a number of outstanding human factors issues that still require attention before data link communication systems can be implemented in the NAS.

4.3. Human Factors Issues

4.3.1. Computer-Human Interface

In contrast to the naturalness of voice communication, the data link capability generally requires keyboard interactions to compose and initiate messages. Keyboard interactions can be notoriously cumbersome and error prone, particularly if messages are long or complex. The interface can also become cumbersome in retrieving previously received messages, if care is not taken in design. In addition, there is some question whether a message appearing on an electronic display commands the same sense of immediacy or urgency as does voice communication. Hence, most proposed data link implementations occur along with distinct auditory alerts that announce the arrival of a new text message. It has been suggested limiting data link implementation only to routine non-time critical situations, such as those proposed for CPDLC Build I and IA.

Another important issue relates to the time required of data link vs. radio/voice-only communications. On the ground side it has been reported that controller delays in responding to pilot requests are approximately 3 seconds longer when presented on an electronic display as compared to voice requests. On the air side, there appear to be few substantial differences in pilot response with the two modes of communication (Wickens, Miller, and Tham, 1996[17]). Pilots appear to respond significantly faster when data link messages are redundantly conveyed by synthetic voice (than by visual display only). However, analysis of total transmission time (i.e., the time between initiation of a message by ATC and receipt of acknowledgment that the message has been received), suggests that this time may be nearly twice as long for a data link system (between 15-20 seconds) as for a voice-only system (around 10 seconds) (Waller and Lohr, 1989[18]; Talotta, 1990[19]). Total transmission time delays tend to be longer with non-routine or complex messages (Lozito, McGann, and Coker, 1993[20]). This can be significant since longer delays reduce communication efficiency. Reduce efficiency, in turn, may lead controllers to “creatively disuse” data link in favor of more rapid radio/voice-only communication.

Given the differences in response time and total transmission time between the two modes of communication, a consensus is emerging that any effective data link system should provide redundant means of transmitting information along either channel. Furthermore, consensus indicates that data link messages (e.g., standard clearances, ATIS messages, routine weather observations and forecasts, reports on the status of facilities and equipment, routine position reports) should be primarily associated with routine, non-time critical situations. This distribution has two advantages: (1) non-routine requests will be delivered over the more attention-getting voice channel; and (2) more unfamiliar and complex communications can be initiated over the more natural voice channel, minimizing the number of keystrokes. In summary, it appears that (on both the ground and air side) data link provides more accurate, but slightly slower communications.

4.3.2. Workload

The workload issues associated with data link represent some of the greatest human factors concerns, both on the flight deck (Corwin, 1991[21]) and on the ground (PHARE, 1996[22]). In each domain, three issues cause concern: (1) what is the workload imposed by the task of initiating and receiving data link communications? (2) what are the implications of increased visual-manual task demands necessitated by conventional data link on ongoing flight or ATC tasks, which are themselves mostly visual-manual? and (3) how does data link affect the distribution and management of workload?

The workload of the data link task itself varies. There is consensus that the composition and initiation of lengthy keystroke messages by either ground or air personnel involve considerably higher workload than spoken messages. This has been a particularly strong complaint among pilots (Gent and Van, 1995[23]). One solution has been to predefine messages such that a more complex but standard message can be sent with a single keystroke. This will generally require constructing a predefined list, prior to a flight, on which the messages would pertain to a particular flight plan. Interestingly, Hahn and Hansman (1992[24]) report that graphic depiction of flight plan routes received from a controller and embedded in an electronic map display imposes a lower workload than either text or spoken instructions describing the particular geometry of the flight plan. Another solution evaluated on the ground side (PHARE, 1996[25]) tries to maximize the intuitiveness of the command interface, via a mouse windowing menu-type interface, in which predefined options can be easily selected and then uplinked. This was shown to have a significant effect in reducing controller workload.

The second workload issue, interference with ongoing tasks, causes concern over the "heads-down time" that occurs as pilots and controllers read data link information. This competition for visual resources is not trivial (Gent and Van, 1995[26], PHARE, 1996[27]). These findings have led to proposals that a primary data link message be supplemented with a synthesized voice transmission of the same material, hence offering all the well-known benefits of redundancy gain. Such a procedure was found to reduce the amount of "heads-down time" spent by the pilot flying the aircraft (Gent and Van, 1995[28]). On the ground side, present design efforts implement downlinked messages visually, as close as possible to the plan view display (either as windows on the margin of the display [PHARE, 1996[29]] or directly incorporated into the flight data blocks or along the pictorial representation of the flight trajectory [Wickens, Miller, and Tham, 1996[30]].

Finally, because data link allows a relatively enduring representation of text (or graphic) information, it should give pilots or controllers more flexibility, for example, in completing high priority, interruption-vulnerable tasks (i.e., checklist procedures). Supporting this conclusion, Lozito et al. (1993[31]) found that pilots were more likely to carry out other tasks, between receipt and response to communications, over data link than over voice channels.

4.3.3. Communication

Another issue pertaining to message delivery itself concerns communication errors that might be committed by keystrokes in a data link system and the error-correcting mechanisms that could prevent these errors from turning into system errors. Currently, the data link system is designed so that the pilot, for example, upon reading a message can respond with a "Wilco" (will comply), implying that the message is understood and will be carried out. However, there is no guarantee that the same problems of expectation (seeing what one expects to see) may not be present here as has been observed with voice communications (hearing what one expects to hear). This issue has not been examined fully. As yet, no specific examination of keystroke errors in data link usage has been carried out to compare, for example, their frequency relative to the frequency of communication errors with a radio/voice-only system (Cardosi, 1993[32]).

It is also possible that data link systems may inhibit the tendency for pilots to follow up messages with requests for clarification, as they often do with radio/voice-only systems. Data link will not permit the passage of nonlinguistic information, such as the sound of urgency in a pilot or controller's voice.

Communication with data link has at least two broader implications. First, considerable concern has been expressed that personalizing the communication channels between a pilot and a controller via data link will deprive other pilots of important party-line information; that is, information that may help them update or maintain their situation awareness of the surrounding airspace (Midkiff and Hansman, 1992[33]; Gent and Van, 1995[34]; Federal Aviation Administration, 1996[35]). The desirability of obtaining such party-line information by pilots has been well documented (Danaher, 1980[36]). Although no negative impacts have been reported as a consequence of the absence of a party-line in data link simulations, a fairly strong recommendation can be made that a data link system should retain the capability of sharing certain forms of critical information (such as weather, particularly in the terminal area). This is consistent with the idea that non-routine information, such as hazardous weather, should be allocated to radio/voice channels.

The second way data link affects communication and teamwork is in the sharing of duties between team members, both on the flight deck and on the ground. On the flight deck, fairly clear lines of responsibility are allocated between the pilot flying the aircraft and the pilot not flying, with the latter having responsibility for monitoring data link messages. However, the pilot flying cannot be expected to ignore data link channels entirely. Furthermore, unless data link messages are redundantly presented via voice synthesis, the pilot flying will be less aware of potentially important uplinked information that would have been shared under a radio/voice channel.

On the ground, FAA simulation studies revealed positive benefits of data link (in load sharing and in the flexibility of distribution of responsibilities) when traffic load becomes quite high (Federal Aviation Administration, 1996[37]; Talotta, 1992a[38], 1992b[39]). Unlike the dedicated radio communicator on the radar-side of the controller workstation with the conventional system, a data link system can allow various operators to assume temporary responsibility for certain aspects of communications.

In simulations, this flexibility has been found to provide an unexpected benefit to control efficiency. It has been reported that this flexibility of loosely defined responsibilities can have its down side. For example, unless careful training of the team in resource management occurs, so that shifts in responsibilities are clearly and unambiguously annunciated, this flexibility will provide little advantage. This was the recommendation of investigators in an FAA simulation study (Federal Aviation Administration, 1996[40]). Parallel findings have also been reported in the flight deck, and have been incorporated into crew resource management training programs (Butler, 1993[41]).

4.3.4. Automation Issues

Data link is a form of computer-based automation. Within the data link system, varying levels of automation have been proposed. Various forms of computer-based automation can assist in message composition, reducing workload (PHARE, 1996[42]). A more critical concept is the possible automatic link between data link and the Flight Management System (FMS). This automatic link requires perhaps one or two keystrokes to create messages without the pilot having to read the message or entering it manually (message gating) (Gent and Van, 1995[43]; Waller, 1992[44]; Knox and Scanlon, 1991[45]).

The gating process can be carried out at three critical levels of automation. At the lowest level, the pilot could read the display, acknowledge with a Wilco keystroke, and then proceed to load the information manually into the FMS. At a higher level of automation, activation of the Wilco key could automatically load the information into the FMS. At a still higher level of automation, such information could automatically be loaded into the system as it is uplinked and affect aircraft performance automatically (the aircraft's trajectory, as an example) unless the pilot intervenes.

There is relatively substantial agreement among pilots that such a gating system is of benefit, both in reducing workload and heads-down time (Gent and Van, 1995[46]) and in reducing the possibilities of keystroke errors when data is entered manually (Gent and Van, 1995[47]; Waller, 1992[48]; Knox and Scanlon, 1992[49]). Nevertheless, two concerns have been noted with such a system. First, it is possible it might lead to complacency and relatively automatic acceptance (and entry in the FMS) of the message, with less careful evaluation than would be done with manual entry. The lessons learned regarding complacency in response to automated actions are well documented. One study (Hahn and Hansman,1992[50]) found that graphic presentation of uplinked routing messages provided a better means for the pilot to identify inappropriate instructions than did text messages. Although there have been no reports of loss of situation awareness by pilots with such a gating option (Gent and Van, 1995[51]) it is important to realize that self-report of awareness is not the same as actual awareness. The second concern is the possibility of designing a system in which the message is automatically loaded into the FMS prior to a pilot's decision with the pilot simply having the authority to activate it. It would appear that this further removal of the pilot from the control loop would be a clear invitation to complacency and loss of situational awareness.

Given the possibilities envisioned by the different levels of gating, it is feasible that a system could be designed that allows alternative gating modes. Such a system will surely invite confusion ("how in the world did I ever get into that gating mode?") and is not recommended. A pilot, for example, may assume that a message was automatically loaded in the FMS (high automation, low gating), when in fact it was not.

4.4. Recommendation

The introduction of data link has profound human factors implications for workload, for communications, and for the overall structure of the NAS, characterized by the relationship between pilots, controllers, dispatchers, and automation. With modest goals, it is possible to envision a system that is designed primarily to provide a visual record of material transmitted by conventional voice channels. At the other extreme, it is possible to envision a scenario in which both human elements, on the ground and in the air, are substantially removed from the control loop, while control is exercised between computers on the ground and in the air. Although planners for CPDLC Build I and IA do not intend such a scenario, the possibility exists that levels of automatic control and gating could be implemented that approximate this kind of interaction in the future. To this end, it becomes important to identify the important human factors issues in order to ask the right kinds of questions for both design and for testing.

5. Operational Safety

5.1. Background

In early August 1998 a decision was made to conduct a preliminary Operational Safety Assessment (OSA) of CPDLC Build IA. The purpose was to identify any "undiscovered risks" that could result in significant cost increases or schedule delays prior to the October JRC.

The analysis adhered to the basic principles established jointly by RTCA SC-189 and European Organization for Civil Aviation Equipment (EUROCAE) WG-53 for conducting an OSA in an Air Traffic Services (ATS) operational environment that uses data communications. The committee conducting the hazard analysis relied on subject matter experts (SME) from various organizations associated with the development of CPDLC. Appendix B contains the CPDLC Build IA Preliminary Operational Safety Analysis Report (POSAR).

5.2. System Safety Engineering

System safety is an engineering process for the identification and management of safety related risks. This process involves various applications and techniques that have evolved over the years. Experience in identifying and controlling hazards has resulted in a recognized discipline with accepted procedures for performing various stages of risk assessment.

The process applied to CPDLC Build IA in this exercise can be described more accurately as a hazard analysis rather than an OSA. The rationale for using this process was based on established safety engineering practice. An OSA, as described in the related RTCA documents, is essentially a high level overview of the entire worldwide aerospace system, including various components such as communications, navigation, surveillance and air traffic management.

By selecting CPDLC as the sole subject of this evaluation, it was determined that a hazard analysis had to be conducted to identify any undiscovered risks inherent in the CPDLC architecture and/or MNS which could result in significant cost increases or schedule delays prior to the October JRC.

It is recognized that an OSA must be conducted on the end-to-end system to determine build requirements and mitigation strategies. This OSA should be initiated immediately following the final modifications or amendments to this hazard analysis in order to remain within the development schedule and budget perimeters for CPDLC deployment.

5.3. Recommendations

After conducting the preliminary hazard assessment, the committee found no CPDLC Build IA safety related issues to stop current plans for the October JRC.

The committee did identify 31 hazard scenarios along with associated hazard controls and mitigations. The committee recommended the following:

- These controls and mitigation should be included in the system requirements.
- The hazard scenarios will be considered unresolved until such time that the mitigations and controls have been implemented formally.
- Identified risks will be adequately eliminated or controlled to an acceptable level.
- Any changes in the CPDLC Build IA design should be evaluated for system safety.
- The risks associated with any future changes should be evaluated for system safety.

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- To complete the risk assessment process, determine likelihood estimates from the results of future system and subsystem hazard analysis.
- System and subsystem hazard analyses are required for the CPDLC system.

6. CPDLC Build I and IA Economic Analysis

The economic analysis considered the following criteria: FAA and user Life-Cycle Costs, FAA and user benefits, net present value (NPV), and benefit-cost (B/C) ratio. All costs are expressed in then year dollars or 1998 present value dollars, whichever is appropriate to the analysis. The analysis was based on "most likely" input values although the inputs for many of the cost categories had a range of values. Risk assessment is a technique used in economic analysis to capture the uncertainties of the input variables. The risk assessment, discussed in depth in Section 7, summarizes the low-confidence and high-confidence values of the different "most likely" cost categories:

- Low-confidence value: The low-confidence value is 20/80 and indicates that there is an 80% chance the actual costs will exceed the estimated costs.
- High-confidence value: The high-confidence value is 80/20 and indicates that there is a 20% chance the actual costs will exceed the estimated costs.

The analysis was initially based on the implementation path recommended by the Data Link Path Team and endorsed by the NAS Modernization Task Force Data Link Team. However, early assessments of program affordability indicated that the recommended acquisition strategy was too ambitious for the funding available in fiscal year (FY) 1999 (FY99) and FY00. As a result, some assumptions had to be changed, four (4) alternative implementation schemes were developed, and the cost estimates adjusted to achieve an affordable, executable program. The alternatives are shown in Table 6-1.

Table 6-1. CPDLC Build I and IA Alternative Implementation Plans

	Option 1		Option 2		Option 3		Option 4	
Deployment	**Key Site**	**National**	**Key Site**	**National**	**Key Site**	**National**	**Key Site**	**National**
Build I	6/02	Yes	6/02	Yes	6/02	No	6/02	No
Build IA	6/03	Yes	12/03	Yes	6/03	Yes	12/03	Yes

These alternative strategies required the IAT to revisit the cost estimate.

- Option 1 was the baseline program as originally planned. The cost estimate detailed in Appendix A was based on this program. Making adjustments to that estimate created the cost estimates for the other alternatives.
- Option 2 called for no changes to Build I but a six-month slip to Build IA implementation. The Build IA delay caused adjustments to software development costs and hardware/ software integration costs with their corresponding funding requirements slipping one-year.
- Option 3 resulted in a more extensive modification to the cost estimate, deleting all costs in Build I associated with national deployment. The estimate increased for Build IA (for the additional software development, hardware/software integration, and other support elements) to cover the national deployment of both Build I and Build IA message sets.
- Option 4 was the same as Option 3 plus a six-month delay in national deployment of Build IA.

Options 2 and 4 were eliminated from further analysis during the CPDLC JRC when the user community advocated not to delay Build IA. Thus, the economic analysis was based on the adjusted costs of Options 1 and 3. Table 6-2 summarizes the results in Present Value (PV) dollars of the CPDLC Build I and IA economic analysis with and without the passenger value of time (PVT).

Table 6-2. Present Value Cost of Estimates at the 20/80% and 80/20% Confidence Level

Options	1: Without PVT		3: Without PVT		1: With PVT		3: With PVT	
	Range	**Most Likely**	**Range**	**Most Likely**	**Range**	**Most Likely**	**Range**	**Most Likely**
PV Costs ($M)	303-367	312	274-336	288	303-367	312	274-336	288
PV Benefits ($M)	276-366	338	259-342	313	505-671	621	475-629	576
NPV ($M)	(72)-40	25	(56)-47	26	164-338	307	166-326	288
B/C Ratio	0.8-1.1	1.0	0.8-1.2	1.1	1.5-2.1	2.0	1.5-2.1	2.0

6.1. Life-Cycle Costs

The estimates represent the life-cycle costs for the acquisition, installation, operation and maintenance, and support as well as user equipage costs for Build I and IA, Option 1 and 3.

6.1.1. FAA Life-Cycle Costs

The cost estimates reflected in Tables 6-3 and 6-4 show the cost summary for Facilities & Equipment (F&E) and Operations & Maintenance (O&M). Numbers include costs for system development, deployment, installation, and operation and sustainment. The VDL-2 air/ground communications subnetwork F&E costs included in this estimate are FAA funded for both uplink and downlink messages in the early years of transition to CPDLC. Appendix A contains the specific details of the scope of the cost estimate, assumptions, and the basis of these estimates.

Table 6-3. Option 1 CPDLC Build I/IA "High Confidence" Cost Estimates (Then-Year $M)

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-15	Total
Build I													
F&E	18.1	16.5	20.1	20.1	11.5	1.9							**88.2**
O&M													
Build IA													
F&E	2.2	10.9	13.1	10.5	14.0	6.1	2.1	1.4					**60.3**
O&M						0.4	0.2	0.1	1.5	1.5	1.5	7.5	**12.7**
VDL-2 (F&E)				0.01	0.04	0.2	1.3	1.8	0.5				**3.8**
Total Program	20.3	27.4	33.2	30.6	25.5	8.6	3.6	3.3	2.0	1.5	1.5	7.5	**165.0**

Table 6-4. Option 3 CPDLC Build I/IA "High Confidence" Cost Estimates (Then-Year $M)

	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-15	Total
Build I													
F&E	15.4	13.2	12.4	7.8	2.9	0.5							**52.2**
Build IA													
F&E	1.5	9.2	13.3	18.9	28.6	24.1	9.3	2.8					**107.7**
Build I+IA													
F&E(w/o VDL-2)	16.9	22.4	25.7	26.7	31.5	24.6	9.3	2.8					159.9
F&E/VDL-2				0.1	0.1	0.4	2.0	3.2	1.0	0.0			6.8
F&E Total	16.9	22.4	25.7	26.8	31.6	25.0	11.3	6.0	1.0	0.0	0.0	0.0	166.7
O&M	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	1.5	1.5	1.5	8.9	13.7
O&M /VDL-2							0.1	1.8	13.1	24.1	32.7	393.2	465.0
Total O&M						0.1	0.2	1.9	14.6	25.6	34.2	402.1	478.7
Total Program	16.9	22.4	25.7	26.8	31.6	25.1	11.5	7.9	15.6	25.6	34.2	402.1	**645.4**
Total VDL-2*	0.0	0.0	0.0	0.1	0.1	0.4	2.1	5.0	14.1	24.1	32.7	393.2	**471.8**

*/ These VDL-2 costs reflect FAA plans to pay for uplink and downlink message costs

6.1.2. User Life-Cycle Costs

User life cycle costs shown in Tables 6-5 through 6-9 include costs for avionics, installation, upgrades, spares, and certification. Costs were calculated based on the following assumptions:

- Life cycle of avionics is 15 years.
- Costs are estimated to equip VDL 2-equipped air carrier, regional/commuter, corporate and low-end general aviation (GA) and military aircraft with CPDLC.
- This estimate assumes that to forward-fit VDL-2/CPDLC capability in new aircraft is a more cost effective solution in transitioning a fleet to CPDLC capability than to retrofit existing aircraft. The rational is that the cost associated with relocating the current ACARS Cockpit Display Unit (CDU) from a position behind the pilot to one more in the pilot's line of sight is more than most airlines would be willing to pay.
- It is estimated that most new domestic aircraft delivered *after the year 2005* will be equipped with at least VDL-2/AOC capability that can be upgraded to VDL-2/CPDLC capability. This involves placing the ACARS CDU in the pilot line-of-sight to facilitate observation of Air Traffic messages, providing a VDL-2-capable radio, and replacing or upgrading the current communication management unit (CMU) to Level C.
- Yearly certification costs were split 60% for VDL-2/AOC and 40% for VDL-2/ CPDLC.
- Approximately 81.7% of the current air carrier fleet and 50% of the regional/commuter/corporate general aviation fleet is equipped with ACARS.

Assumed user equipage rates are listed in Table 6-5, with entries representing the percent of aircraft equipped.

Table 6-5. CPDLC User equipage rates

Year Equipage (%)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Air Carrier	0	0	1	1	1	2	5	12	20	25	29	32	36	39	43	46
Regional/Commuter	0	0	0	0	0	0	0	1	1	2	3	6	13	19	21	24
Corporate GA	0	0	0	0	0	0	0	2	3	4	9	20	29	32	35	39
Other Radio Equipped GA	0	0	0	0	0	0	0	0	0	0	1	2	3	4	5	6
FYI—Overall GA	0	0	0	0	0	0	0	0	0	0	1	3	4	5	6	7
Military	0	0	0	0	0	0	1	2	3	4	5	6	7	8	9	10

Table 6-6 shows the overall user equipage assumptions, by user category, made for this analysis. The table summarizes the total GA equipage and percentage that are corporate and other GA and the percentage of air carriers projected to be equipped with VDL-2 avionics.

Table 6-6. User Total Equipage Assumptions

User	% of Category
Overall GA equipage percent	94
Corporate percent of total GA	5
All other GA	89
Air Carrier overall VDL-2 equipage assumption	80

Table 6-7 contains the total user CPDLC avionics upgrade life cycle costs.

Table 6-7. User Life Cycle Costs (Then-year $M)

Year	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10-15	Total
Costs	0.0	0.5	0.8	1.4	1.4	1.5	2.8	6.1	18.1	17.0	14.1	141.2	205.0

6.1.3. Service Provider Life Cycle Cost

6.1.3.1. Assumptions

All costs were calculated based on the following assumptions and basis of estimate:

- Service provider life cycle costs are costs for VDL-2 service supplied by a commercial provider. Both message costs and overhead transport and application protocol costs are included.
- The cost for both uplink and downlink message were estimated and included in this analysis. At the time of this analysis the FAA had not determined whether it will pay for both uplink and downlink costs, or uplink cost only. Since that time, the JRC decided that the FAA will pay for all messages, uplink and downlink.
- Total life-cycle costs were calculated for 15 years (2000-2015).
- Estimate assumes Service Provider will charge a rate based on data link message traffic (in kilobits per year), and that the Service Provider Kilobit rate will decrease as message traffic increases.
- Estimate assumes initial rate charged to the FAA will not exceed $0.20 per kilobit. In the worst case, the Service Provider will charge an initial rate that will not decrease over time.
- Estimate assumes unsuccessful transmissions do not exceed 5% of all transmissions.

Table 6-8 shows the most likely estimates of messages per flight (including Start messages – one per facility) and message sizes. The average Network Protocol Data Unit (NPDU) message size (in bytes) is the total message size with protocol overhead included. Transport Protocol Data Unit is abbreviated TPDU.

Table 6-8. Average Messages per Flight and Message Sizes

	Build I		Build IA	
All Messages	**Up**	**Down**	**Up**	**Down**
Messages Per Flight	53.9	48.3	94.1	91.3
Average Messages Per Sector	4.49	4.03	7.84	7.61
Average Message Size (bytes)	16.29	8.14	15.50	8.21
Average TPDU Size (bytes)	26.24	18.20	25.04	17.77
Average NPDU Size (bytes)	34.75	27.23	31.63	24.43

Table 6-9 shows average Transport Layer Acknowledgement (T-ACK) message traffic and sizes (bytes). The average NPDU message size includes protocol overhead.

Table 6-9. Estimates of Average Message Traffic and Size

	Build I		Build IA	
All T-ACK Messages	**UP**	**DN**	**UP**	**DN**
Messages Per Flight	53.9	48.3	94.1	91.3
Average Messages Per Sector	4.49	4.03	7.84	7.61
Average Message Size (bytes)	16.29	8.14	15.50	8.21
Average TPDU Size (bytes)	18.00	18.00	18.00	18.00
Average NPDU Size (bytes)	26.51	27.03	24.58	24.66

A complete set of the assumptions and basis of estimates is provided in Appendix A.

6.1.3.1. Methodology

Initial contact with a facility (e.g., ARTCCs) requires a Start Message in uncompressed format. We assumed that a certain percentage of operational messages require Logical Acknowledgements. This assumption is based on two factors: (1) Airways Facilities (AAF) requires Logical Acknowledgement to monitor the Service Provider contractual obligations; and (2) operational requirements require Logical Acknowledgements to ensure message delivery. The most likely logical acknowledgement rate is 30% of all messages.

Service provider costs are directly dependent on user equipage rates. Our assumed equipage rates are listed in Section 6.1.2, User Life-Cycle Costs. Equipage projections assume that data link traffic will be low until at least 2005, and will then increase as more users see benefits and equip with CPDLC.

Initial CPDLC VDL-2 equipage rates (prior to 2010) for airlines are projected to be low for airlines and corporate aviation and very low for the regional air carriers and general aviation. This estimate assumes these initial CPDLC VDL-2 equipage rates (prior to 2010) for airlines and for the regional air carriers and general aviation will increase significantly after 2010. However, if Next-Generation Air/Ground Communication System (NEXCOM) Program Segments II and III are approved, it is estimated that low-end general aviation will equip with NEXCOM VDL-3 radios and will not equip with VDL-2 CPDLC radios.

Flight data was obtained from FAA sources. Average Hours for a flight in en route airspace is derived from the latest *FAA Aviation Forecasts Fiscal Years 1998-2009 (FAA Forecasts)* report for air carriers, regional/commuter airlines, and general aviation. The *FAA Aviation Forecasts* identifies projected total average flight times by year. To account for en route airspace time, 20 minutes is deducted from the yearly average flight time. The number of flights per year is obtained from the *FAA Aviation Forecasts* for air carriers, regional/commuter airlines and commuters, and general aviation. Traffic and CPDLC data link forecasts for the military are not available and FAA cost estimates for military CPDLC communications are not included.

The formula for computing charges to the FAA is as follows:

$$\frac{\$}{\text{KB}} * \frac{\text{messages}}{\text{hour}} * \frac{\text{KB}}{\text{message}} * \frac{\text{hours en route}}{\text{flight}} * \frac{\text{flights}}{\text{year}} * \frac{\text{Percent aircraft}}{\text{CPDLC equipped}} = \$/\text{year}$$

Table 6-10 contains the total service provider life cycle costs.

Table 6-10. Service Provider Life Cycle Costs (Then-year $M)

	FY 02	FY 03	FY 04	FY 05	FY 06	FY 07	FY 08	FY 09	FY 10	FY 11	FY 12	FY 13-15	Total
Uplink	.01	.04	.20	1.3	2.7	7.6	13.1	17.7	21.5	26.3	32.3	132.9	256
Uplink/Downlink	.02	.07	.50	2.1	5.7	14.1	24.0	32.7	39.6	48.6	59.8	245.5	472

6.2. Benefits

As discussed in Section 2.2.2, the Atlanta study is generally acknowledged as the only quantitative study to date for data link benefits in en route airspace, and as such was used as the basis for assessing the benefits of CPDLC Builds I and IA. There were several criticisms of that study that brought its results into question. Those criticisms had to be dealt with if the use of that study was to be considered valid.

The Atlanta study was updated from 1994 ADOC values to 1998 values. This value was originally a mix of Air Carrier values for in flight and ground delays. For this investment analysis, because the data existed for values other than just Air Carriers, the 1998 values were weighted by the equipage percentages identified below. These values are taken from FAA-APO-98-8, *Economic Values for Evaluation of FAA Investment and Regulatory Programs*, and are: $3603 per Air Carrier hour; $848 per Regional/Commuter (Air Taxi) hour; and $565 per GA hour.

The benefits per year are next adjusted for equipage. This adjustment has five aspects:

- Air Carrier (A/C) equipage was determined in consultation with users based upon current ACARS equipage and expected VDL-2 radio replacements. A subset of those replacements formed the basis for the A/C equipage rate. This rate was further modified by a slower rate during the first few years, then followed by expected positive results from the key site tests, a rapid return to the VDL-2 overall expected rate percentage. Once the Air Carrier rate was determined, the Regional/Commuter rates and Corporate General Aviation rates were calculated as delayed and slightly lower versions of the A/C rate.
- The assumed equipage rates of air carriers, regional/commuters, corporate general aviation, and other general aviation (including military) are combined in a weighted average, consisting of a 55/15/15/15 split. This weighted average was based primarily on the flight percentages in the Atlanta study; however, large jet and mid-size jet fleet sizes support a mix similar to this split. Note that this need not be the same equipage rates for

cost determinations…simply that this rate reflects a mix of aircraft flying during those busy times in congested air space.

- In 1997, the FAA published *A Multi-Center NASSM Analysis of the Effects of Data Link Equipage Rates on Voice Communications (NASSIM)*, a study using the NASSIM (NAS simulation) tool. From the NASSIM study, it was shown that a 25% equipage rate yielded the same benefits as if the equipage rate was 50%. Similarly, equipage rates of 50% and 75% yield values of approximately 70% and 90%, respectively.
- Air Traffic members of the Benefits sub-team thought there would be a threshold effect; i.e., controllers would not use Data Link unless there was a significant number of aircraft in the sector. This threshold was hypothesized to be 40 to 60%, but because of the NASSIM results, this was lowered to 20% at the minimum.
- Finally, the benefits were ramped in the first few years, smoothing the threshold, NASSIM, and equipage effects. This reflects the idea that some air carriers would be expected to equip sooner than others, and thus some sectors would reach the threshold minimum and display benefits accordingly.

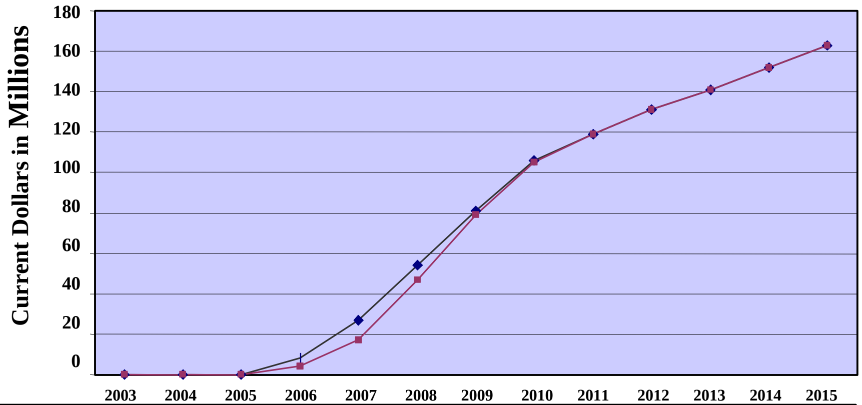
The benefits developed were derived on the above effective percentages.

Adjustments were made to the Atlanta study based upon subsequent criticisms to that work. The criticisms included: The lack of a voice baseline for comparison; and the experiment was unable to distinguish gains from data link versus ordinary gains expected from a learning curve. After discussions with personnel familiar both with the actual experiment as well as typical experiments performed at the Technical Center, it was determined that both of these concerns had minimal impact. Therefore, for the first concern, an assumed decrease of five percent was used to err on the conservative side, with a bound of plus or minus five percent.

For the second concern, it was recognized that full performance level controllers were already familiar with the traffic used in the test. Therefore, this effect would be addressed with risk analysis. Instead of relying on the average results of the three test runs, the original three values would be inserted as high, most likely, and low value variable inputs.

Based upon Air Traffic information, Builds I and IA have been assumed to contribute 60-80% (with a most likely of 75%) of the CPDLC benefits as determined from the Atlanta study. This assumption was based upon the expected message sets, realizing that the first set of messages selected would include some very common messages, thus achieving high value at the start. The next set would contain the next most common group as a useful block, and finally, Build II would contain the remaining set, many of which may be rarely used. However, this final set replaces some of the previous messages with more efficient message options, otherwise this set would be an even smaller portion of the total.

Finally, the benefits were calculated using Crystal Ball and Excel to establish a high confidence estimate. By selecting a 20% threshold of the expected benefits, we construe an 80% confidence level that benefits will meet or exceed the results published below.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Option 1	0	0	0	0	27	54	81	106	119	131	141	152	163
Option 3	0	0	0	4	17	47	79	105	119	131	141	152	163

Figure 6-1. Aircraft Direct Operating Cost without Passenger Value of Time

7. Risk Assessment

Based on knowledge and experience from the Host Data Link (HDL) and CPDLC I/ACARS projects, the IAT identified programmatic risks and mitigation plans. These projects were conducted under the En Route Software Development and Support (ERSDS) contract; the original HDL effort was restructured into CPDLC Build I/ACARS focusing on the capabilities needed to support Free Flight Phase I ACARS trials with Northwest Airlines.

The impact of each risk is assessed in one or more of the following four major categories: Cost, Schedule, Technical, and User Acceptance.

7.1. Software Development

As with any major software development program, there is considerable risk associated with the CPDLC software development. The overall risk assessment for software development is considered to be medium.

Major risk areas for the software development include:

- Accuracy of initial software development costs and schedule (i.e., what is the basis of estimates?).
- Requirements definition (i.e., requirements are unambiguous, complete, concise, testable, etc.).
- Requirements stability.
- Ability of the software design to address and accommodate human factors issues.
- Experience and competency of the contractor to complete the required software development effort.
- Software integration.

7.1.1. Accuracy of initial software development costs and schedule mitigation

Initial CPDLC software development cost and schedule estimates are based on historical CPDLC software development activities (Host Data Link, CPDLC I/ACARS, and previous ATN SARPs validation prototyping activities). This historical information serves as the basis for the functional decomposition of the software (i.e., source lines of code -- SLOC estimate), software complexity, and software development contractor productivity factors. SLOC estimates (High, Most Likely, Low) were developed and converted to dollars using historical average contractor labor rates. Cost and schedule risk assessments for the software development were conducted using the Price-S model. Additional schedule and cost margins were added to the initial estimates to determine 80/20 schedule and cost estimates.

7.1.2. Requirements definition mitigation

The majority of the CPDLC requirements are well defined, since they are contained in the approved ICAO ATN SARPs. Although there will be some changes to the ATN SARPs due to lessons learned in the software development and implementation of ATN, these changes are anticipated to represent a minimal risk. Additionally, there is already an on-going effort to validate the SARPs, which should uncover any problems with the ATN SARPs. Ground automation requirements (beyond the scope of the ATN SARPs) are fairly well defined and understood due to knowledge and experience obtained from previous Host Data Link and CPDLC I/ACARS projects.

7.1.3. Requirements stability mitigation

The CPDLC Build I and IA requirements are well defined in the CPDLC Requirements Documents, the ATN SARPs, and the CPDLC Build IA Functional Specification. Based on the FAA/industry agreed upon incremental approach for En Route CPDLC development and implementation, there is a methodology for defining the scope of each software build. Functional requirements will be baselined at the front end of each software build and will not change unless necessary to satisfy JRC controller performance and/or operational requirements. Where possible, requirement changes will be rolled into the next CPDLC software build.

One area of risk involves the results of the on-going OSA since it is expected to take an additional six months to complete this activity. It is possible that “new” safety related requirements could be identified during the OSA that could impact the CPDLC requirements stability. However, the preliminary Operational Hazard Assessment conducted prior to the JRC Investment Decision date did not identify any new requirements that would impact CPDLC cost and schedule.

7.1.4. Effectiveness of the software design to address controller human factors issues mitigation

Previous CPDLC Human Factors prototyping and software development activities have resulted in the identification of a recommended controller Human Computer Interface (HCI) approach (symbology, referents, keyboard entries) for En Route CPDLC using Plan View Displays (PVDs). National Air Traffic Controllers Association (NATCA) participated in the previous data link activities and made a significant contribution to the identification of the proposed HCI recommendations.

Although some elements of the controller HCI issues need to be re-addressed due to the potential display improvements provided by DSR, the previous data link prototyping activities provide the foundation for the solution of the majority of the controller HCI issues. ARN and NATCA personnel have agreed that the previously identified data link HCI will serve as the basis of the controller HCI for CPDLC I and IA. Human factors prototype activities are planned to support the resolution of the DSR/CPDLC integration issues. Based on the CPDLC I/ACARS software development, there are no major unresolved human factors for the four operational services provided with CPDLC Build I.

The data link symbology issues are expected to be resolved via DSR site adaptation and do not effect DSR or CPDLC software development. The results of the human factors prototyping activities will be rolled into the CPDLC Build IA software development and a future DSR software build (if necessary).

7.1.5. Experience and competency of the contractor to complete the required software development effort mitigation

It is highly likely that the CPDLC software development contractor will be the same contractor who developed the software for Host Data Link and CPDLC I/ACARS. It is anticipated that the contractor key technical personnel for the CPDLC I/ACARS project will also be available to support CPDLC Build I and IA. As a result, the contractor has a wealth of corporate knowledge with Host Computer System software development and CPDLC requirements.

7.1.6. Software Integration Mitigation

Software integration is a major cost/schedule issue for major software development efforts. Experience with the software integration activities (such as CPDLC software integration testing and Host upgrades) associated with the Host Data Link and CPDLC I/ACARS projects have better prepared the CPDLC software development contractor and the FAA to better determine a “realistic” cost/schedule for the integration. Although somewhat aggressive, the CPDLC I and IA integration activities and schedule are consistent with previous experience.

7.2. Integration

There are several major integration efforts associated with the development of the CPDLC end-to-end system:

- Integration of CPDLC functionality into the En Route Host Computer System.
- Integration of the Data Link Application Processor into the En Route Infrastructure.
- DSR/CPDLC integration.
- Integration of ATNSI (ATN Systems, Inc.) provided software into the DLAP.
- Full end-to-end system integration, including the air-ground link.
- Full end-to-end system performance.

7.2.1. Host Computer Integration

The overall Host integration risk is considered as medium. The risk areas are cost, schedule, and technical.

7.2.1.1. Risk

New software to provide the CPDLC functionality must be incorporated and distributed as part of a Host Computer System (HCS) national software release. Software changes for the HCS are typically performed every 12-18 months. HCS software schedules must be coordinated with the En Route Integrated Product Team (IPT) and the Field Automation Requirements Management (FARM) team.

There are processor capability limitations with the existing HCS that may limit the ability of the En Route infrastructure to support CPDLC performance requirements. Immediately prior to the completion of the CPDLC investment analysis, the Host/Oceanic Computer System Replacement (HOCSR) budget was cut significantly; it was not known whether this would result in a schedule impact affecting the CPDLC integration schedule.

7.2.1.2. Mitigation

The ADL Product Team has been coordinating CPDLC requirements and schedules with the En Route IPT and FARM team for several months. As a result, the incremental software build approach and associated schedules for the En Route CPDLC “road map” are well understood. Based on preliminary planning, CPDLC I and IA schedule requirements can be accommodated by the planned Host software release schedules. Due to the size of the CPDLC software and the additional complexity added by other non-CPDLC functions planned for future Host software releases, there is an element of schedule risk associated with FAA Office of Operational Support Service (AOS) being able to develop and deliver the HCS software releases in accordance with the preliminary schedules. Based on previous experience, AOS needs a minimum of six months from the completion of CPDLC Operational Testing until the delivery of the new Host software release to the key site. Host processor capability limitations will be improved with the HOCSR deployment. At this time it is unclear if HOCSR will provide sufficient processing power to fully satisfy all CPDLC capacity/performance requirements. It is anticipated that HOCSR will satisfy the capacity/performance requirements for CPDLC Build I and Build IA given the projected user equipage for the first few years of CPDLC service.

7.2.2. DLAP Integration

The overall DLAP integration risk is assessed as low. The primary area of risk is technical.

7.2.2.1. DLAP Integration Risk

This effort involves the integration of the DLAP with the existing HID/NAS LAN. The DLAP will interface with the HCS via the NAS LAN and HID. The DLAP will interface with National Airspace Data Interchange Network II (NADIN II) via the NAS LAN and NAS router.

7.2.2.2. DLAP Integration Mitigation

The HNL (HID/NAS LAN) interface requirements are well understood. The HOCSR program is not anticipated to impact the existing HNL requirements. Technical risk is further reduced since the HNL contractor is also very likely to be the CPDLC software development contractor.

7.2.3. DSR/CPDLC Integration

The overall DSR/CPDLC integration risk is considered to be medium. Possible areas of risk are: cost, schedule, technical, user acceptance

7.2.3.1. DSR/CPDLC Integration Risk

Controllers will initiate data link commands via the DSR platform. As such, modifications to the DSR platform are needed to provide the CPDLC functionality.

7.2.3.2. DSR/CPDLC Integration Mitigation

The ADL PT has been working closely with the En Route IPT to identify and coordinate CPDLC Computer Human Interface (CHI) requirements. The DSR/CPDLC Keyboard Risk Mitigation Study conducted by a joint CPDLC/DSR team identified a recommendation for the number and placement of CPDLC keys on the DSR keyboard. This CPDLC/DSR team will conduct the CPDLC/DSR prototyping activities necessary to identify and resolve the remaining controller display CHI issues. The preferred CPDLC Build I and IA approach is to incorporate CPDLC functionality via DSR changes to keycap changes and DSR Site Adaptation changes. To mitigate cost and schedule risks, DSR software changes to incorporate CPDLC functionality will not be made unless there are no other viable alternatives. There is a concern that the potential number of CPDLC situations requiring time-sharing in the Full Data Block may exceed the DSR Line Interface Unit (LIU) traffic load threshold. The ADL PT and En Route IPT are coordinating the engineering analysis to examine this issue. The initial assessment is that the time-sharing situation will not occur frequently enough to generate a significant impact to the traffic load for Build I. More in-depth engineering analysis, now anticipated to be completed in 6-9 months, is needed to determine the potential impact for Build IA.

7.2.4. Integration of ATNSI Software

The overall ATNSI software integration risk:is considered to be medium to high. The area of risk is with the schedule.

7.2.4.1. Risk of Integrating ATNSI Software

ATNSI/Aeronautical Communications International (ACI) is developing Router Reference Implementation (RRI) and the CPDLC and Context Management Application (CMA) Application Service Elements (ASEs) software for use in the airborne and ground platforms. It was initially envisioned that the use of the ATNSI software in the FAA DLAP would provide cost and schedule savings. Subsequently, ATNSI has announced software development delays that impact the FAA ground software development schedule.

7.2.4.2. Integrating ATNSI Software Mitigation

There are two separate mitigation approaches that can be used: (1) the CPDLC software development contractor could develop the software to provide the RRI/ASE functionality, or (2) use the existing ProATN software used to support the PETAL II trials. The CPDLC software development contractor has previously developed Open Systems Interconnection (OSI) layers 1-4 software as part of previous ATN SARPs validation activities. As such, the contractor may be tasked to complete the development of this software in accordance with the ATNSI External Interface Documents and port it to the DLAP platform. This software would serve as developmental "comm stack" for DLAP software development and integration. Likewise, the ProATN software could serve as developmental "comm stack". At a later date, the developmental "comm stack" could be replaced by the ATNSI RRI/ASEs. Regression conformance testing and end-to-end interoperability testing, using the CPDLC software development contractor developed HOST and DLAP software with the ATNSI RRI/ASE software, would be required as part of OT&E.

7.2.5. Full end-to-end integration, including air-ground link.

Overall full integration risk is considered to be medium. The risk areas are technical and schedule.

7.2.5.1. End-to-end Integration Risk

The software also needs to be integrated with NADIN II and through to the VDL-2 service provider to ensure that all interfaces are properly understood and implemented and to verify that error conditions and recovery are properly implemented.

7.2.5.2. End-to-end Integration Risk Mitigation

The CPDLC schedule includes early interoperability testing with the service provider and avionics to allow for problems to be identified and corrected during the planned CPDLC software development activities. Risk is reduced by: 1) ensuring that VDL-2 service provider Interface Requirements Documents (IRDs)/ Interface Control Documents (ICDs) are available early during the design phases, and 2) including the VDL-2 service provider at the CPDLC design reviews.

7.2.6. System Performance Requirements

Overall CPDLC system performance risk is assessed as medium. Areas of risk are technical and user acceptance. Mitigation plans are as follows:

The three subsystems that pose the greatest potential risk to satisfying subsystem latency requirements are the VDL-2 subnetwork, avionics equipment, and pilot response time. One of the most significant system performance requirements is the CPDLC ATC message round-trip latency requirement from controller initiation of message transmission to the display of pilot response message to controller.

This system latency requirement has been segmented and allocated to the various subsystems. The two subsystems that pose the greatest potential risk to satisfying subsystem latency requirements are the VDL-2 subnetwork and pilot response time. The allocated latency requirements for the VDL-2 subnetwork have been identified and coordinated with the prospective VDL-2 service provider.

Allocated latency requirements for the avionics equipment will be coordinated with avionics manufacturers. Because the subnetwork will initially be lightly loaded, the prospective VDL-2 service provider believes that the first VDL-2 implementation will satisfy the latency and capacity requirements. As network traffic increases, the service provider may need to implement network enhancements to ensure that ATC message latency and capacity requirements continue to be satisfied. Pilot response time will be affected by the avionics configuration, the air crew resource allocation, and the operational environment. Human factors activities for the airborne platform will be conducted to verify the reasonableness of the time allocated for pilot response. The incremental approach of Build I and IA to the development and implementation of En Route CPDLC will provide the operational experience and insight to determine the set of operational messages that can be reasonably supported by the system infrastructure and the operational environment.

7.3. User Equipage

User equipage risk was judged as low to medium, with possible impacts on cost, schedule, and technical. User equipage will be impacted by:

- ATNSI software development schedule
- Availability of the service provider's VDL-2 network
- Cost of avionics (including certification)
- Perceived and actual benefits
- Requirement for recording

The CPDLC program office must coordinate with and monitor the activities of industry users, ATNSI software development, and the VDL-2 service provider. A successful transition to the En Route CPDLC capability can only occur when all elements of the end-to-end system (FAA ground automation, VDL-2 service provider, and user avionics) are available. Most major airlines are already planning to migrate to VDL-2 AOC service. Additionally, the CPDLC launch airline and their avionics suppliers are planning to participate in the PETAL II trials. Significant delays in user equipage could impact the CPDLC deployment schedule.

The ADL PT will work closely with ATNSI to monitor the RRI software development, a critical element in the ground automation and airborne platforms. The ATNSI software development schedule is an important element to the scheduled availability of the CPDLC avionics for the Launch Airlines and the availability of the service provider's VDL-2 network. Alternatives have been developed to help mitigate the impact of the ATNSI software delivery baselines. ATNSI and the Launch Airline are developing a CPDLC certification plan that can be re-used by other applicants to reduce industry certification costs.

Participation in the PETAL II trials will provide the launch airline, ATNSI, and the FAA experience in CPDLC associated technical and operational issues and greater insight to potential CPDLC benefits.

Existing FAA/industry groups will continue to serve as a viable forum for identifying significant issues and obtaining FAA/industry consensus on solutions. Additionally, a CPDLC Interoperability Team, consisting of FAA and key industry players, will likely be established.

Airlines will base their Build IA decisions on long term cost. Although the National Transportation Safety Board requirement for recording will not become effective until Build II, it will be considered in airline investment decisions. Even if the Flight Data Recorder (FDR) has unused channels, there will be a need to develop a certified interface from the CMU to the FDR.

7.4. Test and Evaluation

The test and evaluation risk is adjudicated to be low to medium. The primary areas of risk are cost, schedule, and technical.

Delays in the delivery of the ATNSI RRI and ASE software will likely impact: (1) integration of the ATNSI software in the DLAP, and (2) the availability of avionics to support the end-to-end interoperability testing. As such, the CPDLC test schedule would likely be impacted. To minimize the impact of an ATNSI software delay, Host software testing would be conducted first using the developmental ATN “comm stack” and prototype avionics and simulators would be used where practical. Regression testing would be conducted at a later date when the ATNSI software is available and ready for testing.

The ADL PT is developing a test strategy to mitigate risks. These efforts include requirements baseline and control, sub-system performance evaluation, Host/CPDLC prototyping, functional systems testing, interoperability end-to-end testing, and operational testing. Interoperability and operational testing will include the use of key site controllers, simulators, user avionics, and the service provider’s VDL-2 network. To implement the test strategy, the William J. Hughes Technical Center will establish test beds for the ground automation and airborne platforms.

The CPDLC I/ACARS OT&E activity will provide significant experience and insight into the issues associated with CPDLC testing. Lessons learned should allow the FAA to better develop and conduct test cases/procedures for the CPDLC ATN Build I and IA test activities.

The CPDLC test strategy will support the incremental software development approach by planning and testing each Host/DLAP software build prior to full HCS software release integration and deployment.

7.5. Security

Security risk is judged to be medium, with areas of concern cost, schedule, technical, and user acceptance.

Application level security mechanisms are not available for Build I and IA; this capability is currently not addressed in the ATN SARPs. Limited physical security and information security safeguards will be incorporated into Build I and IA. The proposed application level security requirements are anticipated to be incorporated into the ATN SARPs in time to support inclusion of this security capability in the CPDLC Build II time frame.

7.6. Operation and Maintenance

7.6.1. VDL-2 service provider costs

Overall VDL-2 Service Provider Cost risk is medium, with the areas of risk being cost and schedule. There are four main areas of risk indicated by sensitivity analysis:

- **Kilobit Rates** - The most important factor is cost per kilobit transmitted, referred to as kilobit rate. Kilobit rates are expected to be on a declining scale, e.g., as traffic increases cost per kilobit decreases. Currently the FAA does not have a contract for Data Link Services. Potential service providers have responded to a RFI with declining kilobit rates. Until a formal contract is in place with a selected Service Provider, there is a medium risk that actual rates contracted will be higher than projected rates.
- **Logical Acknowledgements -** The Data Link Software system will automatically generate a Technical Acknowledgement for every message transmission. This internal software capability ensures all messages sent have been received. In addition, controllers and AF Service personnel can also dictate that messages sent return a Logical Acknowledgement (LACK). This allows the operator to ensure a message has been received in the correct sequence and within the time requirements. Evaluations are being performed to determine what percentage of all messages should receive a LACK. LACKs are actual messages; the higher the rate of LACKs transmitted, the higher the Service Provider costs will be. Sensitivity analysis indicates Service Provider costs are highly sensitive to the LACK rate. Because a required LACK rate has not yet been determined, there is a high risk that Service Provider Costs could be significantly higher.
- **Message Traffic -** Sensitivity analysis indicates usage rate of each Data Link message as a third major cost driver. Projected usage rates for data link messages were estimated; however, model simulation runs have indicated actual traffic rates could be higher than projected. The risk that actual traffic rates are be higher than projected is low to medium.
- **Payment for Uplink/Downlink -** At the time of this analysis there was no policy regarding the payment responsibilities for uplink and downlink service provider message costs. Three options were considered:
    - FAA pays both uplink and downlink message costs;
    - Airlines pay both uplink and downlink message costs;
    - FAA pays uplink costs and airlines pay downlink costs.

The first option would be the most costly with regard to the FAA Operations Budget. The second option would have the least impact. The third option would share the cost between the FAA and users and lessen, but not eliminate, the impact to the budget.

7.6.2. Communications Infrastructure Capacity

Overall capacity risk is judged to be medium. Possible impacts are cost and schedule.

The additional traffic load imposed by CPDLC may exceed the residual capacity of NADIN II, the ARINC Packet Network Gateway, and other elements of the NAS communications infrastructure resulting in the need for an upgrade.

Models developed for assessing the cost of using an air-ground service provider will be modified to incorporate the communication protocol overhead elements needed for ground-ground communications. AOP-400 has conducted a successful preliminary assessment and will use these figures with their capacity planning model and incorporate the results in the Fuchsia Book. Equipage and traffic projection estimates will be reviewed annually as part of the Fuchsia Book update to verify that the actual usage does not exceed the projected trends. The costs for additional NADIN packet switching network (PSN) capacity are included in the APB if required. Similar analysis completed for the service provider consider cost risks low. Schedule risk should be considered a medium but manageable risk.

7.7. Transition

The transition risk is low. Risk areas are cost, schedule, technical, and user acceptance. Several issues affect the transition to and user acceptance of En Route CPDLC:

- Air Traffic concerns – Air Traffic could raise concerns and issues during installation that may require additional time to resolve.
- Training – Additional training for controllers and technicians may be required.
- User Equipage – The lack of a launch airline could delay CPDLC deployment.
- Infrastructure Support – HOCSR and DSR infrastructure may not provide sufficient performance to fully satisfy all CPDLC requirements
- VDL-2 Service Provider – VDL-2 infrastructure may not provide sufficient performance to satisfy CPDLC requirements

The ADL PT will work with the sponsors, industry, NATCA, the Professional Airways Systems Specialists (PASS) union, and site personnel to identify and resolve issues affecting the CPDLC transition. Most issues will be addressed and resolved well prior to the transition phase. CPDLC training will be developed from experience and knowledge acquired from the CPDLC I/ACARS project. Feedback received from the CPDLC I/ACARS training courses will be incorporated in CPDLC I and IA training requirements.

The ADL PT is working closely with the launch airline, its avionics suppliers, ATNSI, and the VDL-2 service provider to monitor the status of all elements of the CPDLC development (FAA and industry) to ensure successful system integration. En Route infrastructure issues are not anticipated to significantly impact Build I and IA activities, but may become more significant for CPDLC Build II.

7.8. Human Factors Risk Assessment

7.8.1. Assessment Progress

Using guidance from the *Human Factors Risk Assessment Guide*, the human factors risk associated with CPDLC Build I and IA is considered in the low end of the medium range. Estimates of CPDLC's I and IA costs to mitigate human factors risks is about 2.3% of project total costs and about 5% of the schedule. These values are well within the range expected to support human factors efforts for CPDLC I and IA.

IPT scheduling indicates that "Free Flight Phase 1 Human Factors Demonstration" will likely be part of Build I Operational Testing and Evaluation. This is scheduled to begin May 2000 and end by January 2001.

Interoperability Testing will have a component addressing the flight deck human factors issues. While the cost and schedule appear to be of the right order of magnitude, the specificity and connection of human factors risk and mitigation action is not well integrated. Nevertheless, we believe this can be handled during development of the Integrated Program Plan for CPDLC.

Section 7. Risk Assessment

Nine risk facets for human factors were identified: usability, operational suitability, user acceptability, cost estimate, benefit estimate, schedule and programmatic, management, funding, and stakeholder risks. Each of the risk facets has ongoing work associated with them. Two facets, benefit estimate, and management/stakeholder risks have little work identified. While substantive work is ongoing, human factors efforts may not be sufficiently integrated to mitigate human factors issues thoroughly. The result is that project deployment milestones may suffer.

Table 7-1 is a summary of extent of existing research reviewed related to CPDLC, analytic and simulation studies as well as ongoing operational testing. The following matrx describes the level of risk mitigation (1-Low, 2-Moderate, and 3-High) already being addressed by these studies for each human factors risk facet or element, as shown on the left side of each matrix.

7.8.2. Mitigation Actions

The Human Factors component of the Integrated Program Plan must integrate and focus Data-Link Human Factors efforts so that key work can be identified and funded, and results integrated sufficiently early to undertake remedial actions prior to national deployment of CPDLC, Build I and IA. The Human Factors work should be completed expeditiously in order to influence development of CPDLC Build I and IA.

The CPDLC PT should establish a Human Factors Working Group involving operational and other stakeholders to ensure consideration and resolution of CPDLC's human factor issues.

Table 7-1. Extent of human factors risk mitigation efforts completed or underway.

Usability	Research/ Analytical Studies	PETALS I & II	FAA Tech Center Simulation Studies	Eurocontrol Simulation Studies	NASA/Other Simulation Studies
Interface Design	2	2	1	1	1
Workstation Layout	1	1	1	1	1
Displays	2	2	1	1	1
Training	1	1	1	1	1
System Testing	3	3	3	3	3
Technical Documentation	3	2	2	3	2
Operational Suitability					
User/Operator	1	1	1	1	1
Automation	3	2	2	2	2
Displays	2	2	2	2	2
User Acceptability					
Task Allocation	3	2	2	2	2
Automation	3	2	2	2	2
Safety/Hazard/Health	1	1	1	1	1
Testing & Documentation	2	2	2	2	2

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8. Affordability Assessment

Considering the CPDLC Build I and IA economic analysis and the risk assessment, the IAT recommended Option 3 as the preferred alternative. The preferred alternative was incorporated into the APB and assessed for affordability.

Table 8-1 illustrates the cost estimate for the CPDLC Preferred Alternative exceeds the funding levels provided in the Capital Investment Plan (CIP). FY98 funding supported development of a different architecture for this program. Since that approach is not being pursued, this FY 98 funding is not considered part of the APB. A separate segment will be created in the CIP for that previous work.

Table 8-1. Affordability Assessment for CPDLC (Then-year $M)

	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04 and beyond	Total
CIP 10/2/98	10.4	15.7	12.3	12.4	12.9	15.8	87.8	156.9
APB	0	16.9	22.4	25.7	26.7	31.5	40.5	163.7
Delta		-1.2	-10.1	-13.3	-13.8	-15.7	47.3	-6.8

The SEOAT determined that lower priority programs must be reduced to fund CPDLC. They will determine which programs are to be reduced for FY 2000 when preparing the reclama to the FY 2000 Office of Management and Budget (OMB) passback later this year. Years 2001 and beyond will be addressed in the FY 2001 budget formulation process. The delta in FY 1999 will be absorbed within the FY99 budget.

Section 8. Affordability Assessment

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9. Architecture Assessment

ASD-100 conducted an assessment of the recommended approach after reviewing the NAS Architecture V4.0. The assessment had two primary purposes:

1. Determine whether the recommended approach is consistent with the architecture, and identify any necessary corrective action.
2. Use the dependencies identified in the architecture to help assess programmatic risk.

As shown in Figure 9-1, CPDLC Build I and Build IA are part of an overall progression of CPDLC capabilities, but no other data link capabilities are dependent on these earlier builds.

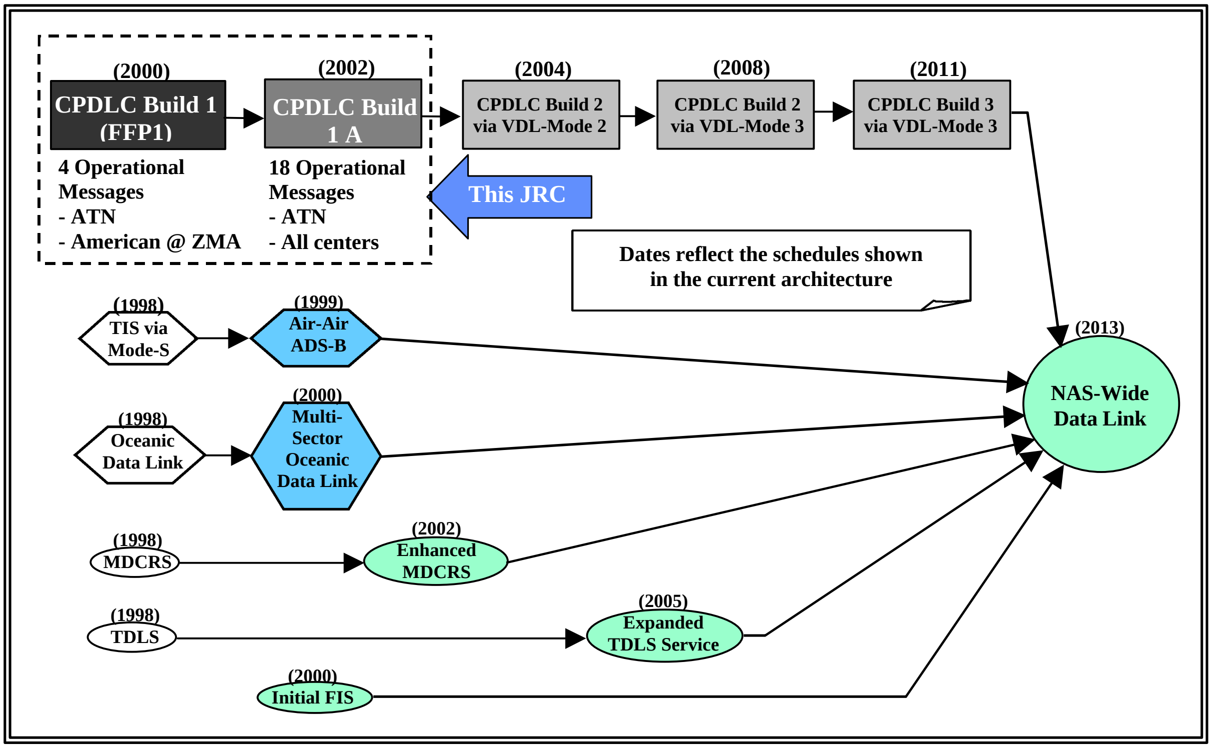

Figure 9-1. Data Link Capabilities Evolution

Because the architecture dates were based on the recommendations of the Data Link Path Team, the architecture IOC occurs in December 2001, which is six months earlier than the revised IOC date of June 2002.

The cost and schedule risk for each of the organizations and activities on which the project is dependent were assessed using a red-yellow-green rating system. In Table 9-1, an entry in a block indicates that there is a dependency. A yellow ("Y") or red ("R") shows that there is a potential problem.

Section 9. Architecture Assessment

Table 9-1. CPDLC Build I/IA Architecture Assessment

Organization	DRS	HOCSR	HID/NAS LAN	DLAP –En Route	NADIN PSN	ARINC Comm Gateway	Comm Service Provider	ATN Comm SW	VDL-2 ATN Avionics	Avionics Certification	ATC Procedures	ATC Training	Pilot Procedres
AND-720			G	G			Y				G	G	
AUA-200	G	R	G										
AOP-400					G								
AOP-500/600						Y							
ATO-400											G	G	
AIR-130										Y			
AFS-400													G
ATNSI								Y					
American Airlines									G	G			G
ARINC							Y						

ARINC Communications Gateway and Communications Service Provider are shown as yellow because the messaging costs have not been negotiated and could also exceed estimates if usage grows faster than expected; these costs would be borne by AND-720 initially, as F&E, and would transition to AOP-600, using Ops funding.

Avionics Certification is shown as yellow because the Operational Safety Assessment has not been completed, resulting in a risk that software development practices might need to be adjusted to accommodate the required design assurance levels.

HOCSR is shown as red because a significant budget cut was imposed shortly before the JRC. This assessment was based on uncertainty over the impact on schedules, since CPDLC is dependent on the HOCSR software release schedule.

10. Next Steps

The CPDLC IAT recommends the following activities be initiated:

- Develop a Draft Acquisition Strategy Paper between November 1998 and December 1998.
- Award the CPDLC I Software Development Task Order by December 1998.
- Conduct ATNSI Software Tiger Team Assessment between October 1998 and December 1998.
- Develop the Draft Integrated Program Plan between January 1999 and April 1999.
- Complete the Operational Safety Assessment between November 1998 and April 1999.
- Begin Operation Test and Human Factors activities for CPDLC I/ACARS between April 1999 and September 1999.

Section 10. Next Steps

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11. Recommendations

The CPDLC IAT recommends the following to the JRC:

- Reaffirm the need for the CPDLC program initiative.
- Affirm the segmentation "Build" approach to the CPDLC program.
- Affirm the recommendation for VDL Mode 2 as the Preferred Alternative for CPDLC Build I and IA.
- Approve the Investment Decision for CPDLC Build I and IA.
- Approve the proposed CPDLC APB for Build I and IA.
- Assign the CPDLC program to AND-700 for implementation.
- Assign responsibility for determining FAA policy for payment of VDL-2 communications service provider costs.

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12. Glossary

Term/ Acronym	Definition	Page
A		
AAF	Airway Facilities	26
ACARS	Aircraft Communications Addressing and Reporting System	4
ACI	Aeronautical Communication International	33
ADL	Aeronautical Data Link	2
ADLS	Aeronautical Data Link System	1
ADOC	Aircraft Direct Operating Costs	7
AMS	Acquisition Management System	1
AOC	Airline Operational Control	4
AOS	Office of Operational Support Service	32
APB	Acquisition Program Baseline	1
ARINC	Aeronautical Radio, Inc.	2
ARS	Air Traffic Systems Requirements	9
ARTCC	Air Route Traffic Control Center	5
AS	Altimeter Setting	2
ASD	Systems Architecture and Investment Analysis	9
ASD-400	Director, Investment Analysis Staff	2
ASE	Application Service Element	33
ASQP	Airline Service Quality Performance	6
ATC	Air Traffic Control	1
ATIS	Airport Terminal Information Services	13
ATM	Air Traffic Management	1
ATN	Aeronautical Telecommunication Network	7
ATNSI	ATN Systems, Inc.	31
ATS	Air Traffic Services	19
A/C	air carrier	27
B		
B/C	Benefit/Cost	21
C		
CBA	Cost Benefit Analysis	5
CDU	Cockpit Display Unit	23
CHI	Computer Human Interface	32

Section 12. Glossary

Term/ Acronym	Definition	Page
CIP	Capitol Investment Plan	41
CMA	Context Management Application	33
CMU	Communications Management Unit	23
CNS/ATM	Communications, Navigation, and Surveillance/ Air Traffic Management	1
CPDLC	Controller-Pilot Data Link Communications	1
D		
DLAP	Digital Link Applications Processor	10
DLORT	Data Link Operational Requirements Team	1
DSR	Display System Replacement	4
E		
EATCHIP	European Air Traffic Control Harmonization and Integration Program	6
ERSDS	En Route Software Development and Support	29
EUROCAE	European Organization for Civil Aviation Equipment	19
F		
FAA	Federal Aviation Administration	1
FARM	Field Automation Requirements Management	31
FDR	Flight Data Recorder	35
F&E	Facilities & Equipment	22
FIS	Flight Information Service	2
FMS	Flight Management System	17
FOC	Final Operational Capability	4
FRD	Final Requirements Document	1
FY	Fiscal Year	21
G		
GA	general aviation	23
H		
HCI	Human Computer Interface	30
HCS	Host Computer System	31
HDL	Host Data Link	29
HID	Host Interface Display	10
HNL	HID/NAS LAN	32
HOCSR	Host/Oceanic Computer System Replacement	31
I		
IA	Investment Analysis	2
IAR	Investment Analysis Report	1

Section 12. Glossary

Term/ Acronym	Definition	Page
PHARE	Program for Harmonized Air-traffic Research	14
POSAR	Preliminary Operational Safety Analysis Report	19
PSN	Packet Switching Network	37
PT	Product Team	3
PV	Present Value	21
PVD	Plan View Display	30
PVT	Passenger Value of Time	21
R		
RFI	Request for Information	10
RRI	Router Reference Implementation	33
S		
SARPs	Standards and Recommended Practices	3
SEOAT	Systems Engineering/Operational Analysis Team	1
SLOC	Source Lines of Code	29
SME	Subject Matter Experts	19
T		
TRACON	Terminal Radar Approach Control Facility	6
TDLS	Terminal Data Link Services Replacement	2
TOC	Transfer of Communication	2
TPDU	Transport Protocol Data Unit	25
T-ACK	Transport layer Acknowledgement	25
V		
VDL	Very High Frequency Digital Link	2
VDL-2	Very High Frequency Digital Link Mode 2	2
VHF	Very High Frequency	9
W		
Wilco	Will Comply	16

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The following list of documents and reports were reviewed and provided background data in the development of the CPDLC Build I and IA Investment Analysis Report. They are listed in chronological order (date of publication).

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Section 14. Endnotes

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Appendix A. Basis of Estimate for CPDLC Build I and IA

A-1. Overview

This appendix documents the methodology used to develop the baseline estimate. The cost estimate was developed by AND-720 and reviewed by ASD-400. This cost estimate represents the “most likely” cost. It **does not** include the adjustments made to it prior to the economic analysis. These adjustments are described in the Economic Analysis Section of this report. Nor does it include the cost risk methodology and assumptions used to derive the “high confidence estimate” reflected in the cost estimate summary tables. The risk methodology will be described later in this appendix.

A-1.1. WBS 3.0, Basis of Estimate for FAA costs

The following documents the basis of estimate and methodology used to develop the cost estimates for CPDLC Build I and IA by Work Breakdown Structure (WBS) element.

A-1.1.1. WBS 3.1, Program Management

The program management effort associated with CPDLC Build I, e.g., business and administrative planning, organizing, directing, coordinating, controlling, and approving actions intended to accomplish overall program objectives. It includes:

- work planning, authorization, and management,
- program control,
- and, contract management.

The estimate of $150K per man-year (developed by AND-720 and reviewed by ASD-400) is based on an engineering assessment of the man loading required to accomplish the task.

WBS 3.1.1, Work Planning, Authorization, and Management

The activities required to develop the strategy for developing, implementing, and executing the program. AND-720 estimates Build I requires two (2) man-years per year from 1999 through 2002 and one (1) man-year in 2003. Build IA requires one (1) man-year of effort in 2003, two (2) man-years in 2004, and one (1) man-year in 2005.

WBS 3.1.2, Program Control

The activities required to ensure all cost, schedule, performance, and benefit objectives are met. AND-720 estimates the Build I effort to be one (1) man-year per year from 1999 through 2004.

WBS 3.1.3, Contract Management

All activities associated with the award and management of project-related contracts. AND-720 estimates the Build I effort as one (1) man-year per year from 1999 through 2002 and 0.5 man-years in 2003 and 2004. For Build IA, they estimated one (1) man-year in 2003, one (1) man-year in 2004, and 0.5 man-year in 2005.

WBS 3.1.4, CMM process improvement

AND-720 estimates one (1) man-year of contractor support effort to achieve capability maturity model (CMM) level 2 and level 3 each year from 1999 through 2003.

A-1.1.2. WBS 3.2, System Engineering

All technical and management activities associated with solution development. These activities include directing and controlling a totally integrated engineering effort of the solution.

WBS 3.2.1, System Requirements and Definition

The engineering effort necessary to transform performance requirements into specifications and preferred solution configuration. The effort develops and maintains design criteria and prepares and maintains system-level documentation and change proposals.

AND-720 estimates for Build I three (3) man-years of effort each year from 1999 through 2001, two (2) man-years of effort in 2002, one (1) man-year of effort in 2003, and 0.5 man-years in 2004. There is an additional effort required to perform these tasks (associated with ARS, ATO, and other AND requirements) of three (3) man-years each year from 1999 through 2001. ACT-350 estimates specification development and production review readiness support will expend 0.5 man-years of effort in 1999 and 2000.

For Build IA, AND-720 estimates one (1) man-year in 2002, two (2) man-years in 2003, three (3) man-year in 2004, and 1.5 man-years in 2005. The additional effort required to perform these tasks because of associated ARS, ATO, and other AND requirements is estimated at one (1) man-year of effort in 2002, two (2) man-years of effort in 2003, one (1) man-year of effort in 2004, and 0.5 man-years in 2005. ACT-350 estimates specification development and production review readiness will expend 0.5 man-years of effort in 2000, .25 man-years in 2001, and .2 man-years in 2002.

WBS 3.2.2, Analysis, Design, and Integration

The only requirement identified by ACT-350 is the design effort for the ATN router at a cost of 0.5 man-year in 1999.

WBS 3.2.3, Value Engineering

A rough order of magnitude (ROM) estimate based on engineering judgment for anticipated engineering change proposals. Build I estimate is $600K in 2001 and $400K in 2002. The Build IA estimate is $600K in 2002 and $400K in 2003.

Costs include AVR support for system certification. AVR estimates Build I requires one (1) man-year of effort for each year from 1999 through 2001 and Build IA requires one (1) man-year of effort each year in 2003 and 2004.

WBS 3.2.4, Supportability, Maintainability, & Reliability Engineering

No requirements were identified.

WBS 3.2.5, Quality Assurance Program (CMM implementation)

All activities associated with development of planning, procedures, examinations, and tests to insure the implementation of CMM meets standards and specifications. AND-720 estimates 0.5 man-years of support in 1999, and one (1) man-year of effort in 2000 through 2003.

WBS 3.2.6, Configuration Management (CMM implementation)

All activities associated with establishing, monitoring, and administering change control procedures to insure proper and traceable implementation of CMM. AND-720 estimates 0.5 man-years of support in 1999, and one (1) man-year of effort in 2000 through 2003

WBS 3.2.7, Human Factors

Costs captured under Build IA include all activities required to define all man-machine interface issues, operational effectiveness, safety, training, etc., for both Build I and IA. ACT-350 estimates this effort at approximately ten (10) man-years of effort in each year in 1999 and 2000, 2.5 man-years in 2001, and 2.5 man-years in 2002

WBS 3.2.8, Security

All efforts and activities associated with security requirements and issues. AND-720 estimates two (2) man-years of effort each year from 1999 through 2002 for Build I. For Build IA, the estimate is one (1) man-year in 2000, two (2) man-years in 2001, and one (1) man-year in 2002. In support of Build IA, ACT-350 requires 0.5 man-years of effort in 2001.

A-1.1.3. WBS 3.3, HW/SW Design, Development and Production

The costs for design and development of hardware, software, and associated integration, assembly, checkout and production.

WBS 3.3.1, Hardware Design and Development

The detailed design, fabrication, assembly, and checkout of all system hardware. AND-720 support for Build I is estimated at two (2) man-years each year from 1999 through 2001. For Build IA, AND support is estimated at two (2) man-years in each year from 2002 through 2004, and 0.5 man-years in 2005. Build IA also includes 0.5 man-years of effort in 2000 and one (1) man-year of effort each year from 2001 through 2003 for AOS support.

WBS 3.3.2, SW Design/Development

Software development costs for detailed design, prototyping, development, and unit level checkout of all Computer Software Configuration Items. Cost estimates were developed using the “Price S” software cost estimating model based on inputs of source lines of code, complexity, developer's experience, and development environment. Estimated source lines of code for both the DLAP and the Host computer are summarized in Tables A-1 through A-4.

In addition, support is required from ACT-350. The estimate for this support for Build I is 1.3 man-years in 1999 and 0.8 man-years in 2000. For Build IA, ACT-350 estimates the effort requiring 2 man-years in 2000 and 1.2 man-years in 2001.

WBS 3.3.3, HW/SW Integration, Assembly, Test and Checkout

All activities associated with development, site integration, assembly, and checkout of the hardware, software, and telecommunications components. Included is funding for DSR integration (DSR development and site implementation costs), Host integration support, Post Functional Configuration Audit (FCA), and CPDLC software development contractor support (regression testing and OT&E). Annual costs were provided by the IPT and appeared reasonable.

FAA support for this task is required for Build I. AOS estimates their level of effort to be two (2) man-years in each year in 1999 and 2000; AND-720 estimates one (1) man-year in 1999 and two (2) man-years in 2000; and ACT-350 estimates approximately 0.6 man-years is needed in 1999.

For Build IA, no additional support is required.

Appendix A: Basis of Estimate for CPDLC Build I and IA

Table A-1. CPDLC Build I DLAP Software source line of code estimates

SLOC - source line of code		SLOC Estimate		
Item	**CSCI**	**Low**	**Most Likely**	**High**
CPDLC - User	DLAP	2,000	3,000	4,000
CPDLC - ASE	DLAP	2,400	3,600	4,800
CMA - ASE	DLAP	1,525	2,250	3,000
CMA Application New Development	DLAP	2,500	3,750	5,000
CMA Application SARPs Services	DLAP	1,500	2,250	3,000
ULA – V4.0 SARPs Compliance and adaptation	DLAP	1,000	1,500	2,000
ULA – port of prototype	DLAP	8,100	12,000	16,000
ULA – hardening	DLAP	8,100	12,000	16,000
FDDI glue - TP4	DLAP	1,000	1,500	2,000
DLP Simulators/Tools Port	DLAP	15,000	22,500	30,000
DLAP DR&A changes	DLAP	4,000	6,000	8,000
AIR Sim (tools) changes	DLAP	1,000	1,500	2,000
NAS Comm changes – remove/replace ACARS specifics	DLAP	500	750	1,000
NAS Comm changes for ATN addresses	DLAP	400	600	800
Menu Build changes – relationship to FT elements rather than PDM message types	DLAP	300	500	600
Additional System Data Collection and Reporting for System Monitoring	DLAP	500	750	1,000
Total DLAP		49,825	74,450	99,200
For Worst Case, assumed required porting of DLAP-II comm stack	DLAP	113,000	150,700	226,000

Table A-2. CPDLC Build I Host Software source lines of code estimates

CPDLC Build I Table A-2(a)		SLOC Estimate		
Item	CSCI	Low	Most Likely	High
HC/DLAP interface changes	HCS	1,500	3,000	4,000
Accept/store ATN addresses	HCS	1,000	2,000	3,000
Forward Accept ATN addresses	HCS	600	1,200	1,200
NDA Processing	HCS	1,000	1,600	2,000
Test Tool changes	HCS	500	1,600	2,000
IC Changes – Handle NALT, display NALT, handle all downlink before Wilco	HCS	1,000	2,000	3,000
Return session processing (ATN vs ACARS "pseudo session"	HCS	1,000	2,000	3,000
Restore end-service processing to ATN requirements	HCS	1,000	2,000	3,000
Total HCS		7,600	7,600	22,100

Table A-2(b)

Assembly		
Low	Most Likely	High
937	**Low**	**Most Likely**
625	1.249	1,874
375	750	750
625	999	1,249
312	999	1,249
625	1,249	1,874
625	1,249	1,874
625	1,249	1,874
4,747	**9,619**	**13,242**

Table A-2(c)

Jovial		
Low	Most Likely	High
563	1,126	1,501
375	751	1,126
225	450	450
375	601	751
188	601	751
375	751	1,126
375	751	1,126
375	751	1,126
2,853	**75,782**	**7,958**

Table A-3. CPDLC Build IA DLAP Software source lines of code estimates

CPDLC Build IA		SLOC Estimate		
Item	CSCI	Low	Most Likely	High
CPDLC - User	DLAP	2,000	4,000	6,000
CPDLC - ASE	DLAP	2,400	4,800	7,000
ULA – V4.0 SARPs Compliance and adaptation	DLAP	1,000	2,000	3,000
Completion of menu service uplink/response support	DLAP	1,000	2,000	3,000
Completion of Build IA messages	DLAP	1,500	3,000	4,000
Enhanced DLAP Recording/DR&A for Build IA	DLAP	1,200	2,500	3,500
RPR-xxxx compliance for Build IA (graphical analysis)	DLAP	1,000	2,000	3,000
Menu Build changes – relationship to FT elements rather than PDM message types	DLAP	300	600	1,000
Additional System Data Collection and Reporting for System Monitoring	DLAP	300	1,200	2,000
Total DLAP		10,900	22,100	32,500

Table A-4. CPDLC Build IA Host Software source lines of code estimates

CPDLC Build IA		SLOC Estimate		
Item	CSCI	Low	Most Likely	High
Completion of Build IA Messages	HCS	1,000	2,000	3,500
Additional adaptation	HCS	1,000	2,000	3,000
Software support upgrades	HCS	500	1,000	2,000
HCS/DLAP interface enhancement for Build IA	HCS	1,500	3,000	4,000
DYSIM Enhancements	HCS	1,000	2,000	2,500
Test Tool changes	HCS	500	1,000	1,500
IC Changes – Handle NALT, display NALT, handle all downlink before wilco	HCS	1,000	2,000	2,500
Total HCS		6,500	13,000	19,000

Table A-4(b)

Assembly		
Low	Most Likely	High
937	1,874	2,499
625	1.249	1,874
375	750	750
625	999	1,249
312	999	1,249
625	1,249	1,874
625	1,249	1,874
625	1,249	1,874
4,747	**9,619**	**13,242**

Table A-4(c)

Jovial		
Low	Most Likely	High
563	1,126	1,501
375	751	1,126
225	450	450
375	601	751
188	601	751
375	751	1,126
375	751	1,126
375	751	1,126
2,853	**75,782**	**7,958**

A-1.1.4. WBS 3.4, Facilities & Physical Infrastructure Design & Development

All national (non-site specific) activities associated with the design and development of facilities and infrastructure. These costs were provided by ACT-350 for the following efforts.

- Tek Decoder Development
- Acquisition of two (2) Data Link Application Processors (DLAP) development systems
- Maintenance for two (2) DLAP development systems
- Upgrade to Tekelek
- Other miscellaneous equipment

A-1.1.5. WBS 3.5, Test and Evaluation

Test evaluation activities necessary to verify and validate that the system meets specifications, satisfies requirements, and is operationally effective and suitable.

WBS 3.5.1, System Development Test and Evaluation

All activities necessary to plan, conduct, and document interoperability testing of additional services and avionics. Prior to software rollout of the Build IA service set, each message type will be validated using the avionics capability at the FAA Technical Center. ACT-350 estimates this effort requiring 1.3 man-years in 1999 and 2.2 man-years in 2000 for the Build I effort. AND support for this effort is estimated at one (1) man-year in 1999 and 0.5 man-years in 2000.

For Build IA, the ATC-350 test effort is estimated to be 0.2 man-years in 2000 and 0.9 man-years in 2001. The associated AND support is estimated at one (1) man-year in 2000 and 0.5 man-years in 2001.

WBS 3.5.2, System Operational Test and Evaluation

All activities necessary to plan, conduct, and document system operational testing to evaluate the systems utility, operational effectiveness, operational suitability including computer-human interface, and supportability. ACT-350 estimates 1.3 man-years in 1999 and 2.2 man-years in 2000 for the Build I effort. AND support for this effort is estimated at one (1) man-year in 1999 and 0.5 man-years in 2000.

For Build IA, the ATC-350 test effort is estimated to be 0.2 man-years in 2000 and 0.9 man-years in 2001. The associated AND support is estimated to require one (1) man-year in 2000 and 0.5 man-years in 2001.

A-1.1.6. WBS 3.6, Documentation

All activities associated with production, delivery and review of FAA programmatic documents and contractor documentation deliverables. Included are the management, coordination, editing, scheduling, auditing and assembly of documents and review packages necessary to the functioning of the program. It includes acquiring, writing, assembling, reproduction, packaging and shipping the data. It also includes the activities involved in converting data from contractor format into government format, as well as reproducing and shipping the data. Specific examples include all technical data, logistics and maintenance data, management data, etc.

The effort for Build I is estimated as requiring the level of effort shown in Table A-5 and A-6.

Table A-5 Estimated staff-years by organization for CPDLC Build I documentation

Organization	1999	2000	2001	2002	2003	2004	Total
ACT-350		0.2					0.2
AFZ-100	0.3	0.5	0.6	0.4	0.2		2.0
AFZ-200	0.3	0.3	0.3	0.2	0.2		1.3
AML-200	1.4	2.0	3.5	2.3	1.1		10.3
AND-720	0.8	1.5	1.7	1.5	0.2		5.7
AOS-300	1.5	2.7	1.8	2.4			8.4

Table A- 6 Estimated staff-years by organization for CPDLC Build IA documentation

Organization	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
ACT-350	0.2											0.2
AFZ-200			0.2	0.1								0.3
AML-200	2.0	3.5	2.3	1.1								10.3
AND-720	1.5	1.7	1.5	0.2								5.7
AOS-300	2.7	1.8	2.4									8.4

A-1.1.7. WBS 3.7, Support

All activities associated with the acquisition of test and measurement equipment, support and handling equipment, support facilities, initial spares and repair parts, and the training required to support and maintain the system or portions of the system through the complete delivery of the solution, but not directly engaged in the performance of the system mission.

WBS 3.7.1, Logistics Support Planning

All planning activities associated with fulfilling the requirements to provide logistics support to the solution. Develop plans to provide integrated logistics support for CPDLC Build I systems. Assess and evaluate the number and skill levels of people required to operate, maintain, and provide training for the CPDLC system, utilizing the guidance of Chapter 3, FAA Order 1380.40C, Airway Facilities Sector Level Staffing Standard System.

AND-720 estimates the level of effort required for Build I logistics planning to be 1.7 man-years from 1999 through 2001, and one (1) man-year in 2002. Build IA is estimated at 0.3 man-years of effort in 2000, 0.2 man-years in 2001, and 0.3 man-years in 2002 and 2003.

WBS 3.7.2, Test and Measurement Equipment Acquisition

All activities associated with the acquisition of test and measurement equipment, which is used to evaluate operational conditions of a system or equipment at all levels of maintenance. It includes the test measurement and diagnostic equipment, precision measuring equipment, automatic test equipment, manual test equipment, automatic test systems, test program sets, appropriate interconnect devices, automated load modules, tap(s), and related software, firmware and support hardware. Packages that enable line or shop replaceable units, printed circuit boards, or similar items to be diagnosed using automated test equipment are included.

AND-720 estimates the level of effort required for Build I test equipment acquisition to be 1.1 man-years in 2000, 1 man-year in 2001 and 2002, and 0.4 man-years in 2003. There are no requirements for Build IA.

WBS 3.7.3, Support and Handling Equipment Acquisition

All activities associated with acquiring tools and handling equipment used for support of the mission system. Equipment typically included is ground support equipment, vehicular support equipment, powered support equipment, materiel handling equipment, and software support equipment, both hardware and software.

AND-720 estimates the level of effort required for Build I support and handling equipment acquisition to be 0.4 man-years in 1999, 0.3 man-year in 2000, 0.3 man-years in 2001, and 0.3 man-years in 2002. There are no requirements for Build IA.

WBS 3.7.4, Support Facilities Construction / Conversion / Expansion

All activities associated with construction, conversion, or expansion of support facilities for training, testing, inventory, contractor and FAA depot maintenance, hazardous waste management, etc. required for the specific system.

No requirements were identified.

WBS 3.7.5, Support Equipment Acquisition / Modification

All activities associated with acquisition or modification of support equipment or software for training, testing, inventory, contractor and FAA depot maintenance, hazardous waste management, etc. required for the specific system.

No requirements were identified.

WBS 3.7.6, Support Facilities. And Equipment Maintenance

All activities associated with maintenance of support facilities and equipment for training, testing, inventory, contractor and FAA depot maintenance, hazardous waste management, etc. required for the specific system prior to the in-service decision.

ACT-350 estimated this effort to require the equivalent of 7.8 man-years in 1999. No requirements were identified for Build IA.

WBS 3.7.7, Initial Spares and Repair Parts Acquisition

Activities associated with the acquisition, provisioning, packaging, handling, storage and transportation of deliverable spare components, assemblies and subassemblies used for initial replacement purposes in the system hardware. Includes repairable spares and parts required as initial stock to support and maintain newly fielded systems or subsystems, including pipeline quantities, during the initial phase of service at all levels of maintenance and support.

Sparing is based on an initial deployment of one, fault tolerant Data Link Application Processor (DLAP) to each Air Route Traffic Control Center (ARTCC) site (20 DLAPs). This also includes an additional 20% for Depot Spares.

WBS 3.7.8, Initial Training

All activities associated with designing, developing, and delivering training services, aids, and materials used to train site technicians, depot technicians, engineers, air traffic controllers, and other personnel.

ATX-100 estimated the backfill overtime costs for controller training as $375K/site for 20 ARTCCs for both Build I and IA.

Based upon past experience, AFZ-100 estimated AF training would consist of a single course comprising both lectures and laboratory exercises approximately 30 - 40 hours in duration for the following number of personnel from their respective organizations.

- AF ----------- 147
- AOS --------- 5
- AMA -------- 2
- NASNOM --- 294

AF training would consist of a single course comprising both lectures and laboratory exercises approximately 30 - 40 hours in duration. For AT personnel, training would most likely consist of three distinct elements:

1. Lecture(s) approximately 4 - 8 hours in duration;
2. Computer Based Instruction (CBI) approximately 6 - 10 hours in duration;
3. Dynamic Simulation (DYSIM) training approximately 2 - 3 hours in duration per ARTCC sector. It should be noted that DYSIM training must be tailored for each location. Since CPDLC will be deployed to 20 different ARTCC sites, each with at least eight sectors, this equates to 240 - 300 total hours of unique DYSIM training to be developed. It is assumed that CBI development costs are about $30K per hour of CBI instruction. It is further assumed that DYSIM development requires approximately two staff months per hour of DYSIM instruction.

For both the AF, AT, and AVR training, these costs include:

- Task and Skills Analysis (TASA),
- Training Plan, Course Design Guide (CDG),
- Course Schedule,
- Lesson Plans,
- Instructor and Student Materials,
- Computer-Based Instruction (CBI) Lesson Specifications,
- CBI Validation Plan and Validation Report,
- Storyboards/Scripts,
- CBI Program Documentation,
- Interactive Courseware for Training Devices,
- Course Walk-Through,
- First Course Conduct and Course Report, Dynamic Simulation (DYSIM) Scripts and Software,
- DYSIM Overview Presentation Package,
- Student Examinations, Final Examinations, and CPDLC Performance Examination,
- TASA and CBI course development for AVR inspectors.

A-1.2. WBS 4.0, Implementation

A-1.2.1. WBS 4.1, Program Management

WBS 4.1.1, Work Planning, Authorization, and Management

All tasks associated with work planning, authorization and management, program control, and contract management. The estimated staffing for this effort is as follows.

Table A-7. Estimated man-years of effort by organization for Program Management

	Organizaation	2001	2002	2003	Total
Build I	AND-720	0.8	2.2	0.9	3.9
	AVR	1.0	1.0		2.0
	ANI	0.05	0.5	0.5	1.05
Build IA	AND-720	0.4	1.1	0.5	2.0
	ANI	0.01	0.1	0.2	0.3

Estimates are for F&E. Assumptions include $2K per site for site prep and overtime (OT) labor. The assumed breakout of sites each fiscal year is: FY 02 (1 site), FY03 (9 sites), FY04 (10 Sites).

Another effort identified is certification implementation. Table A-8 reflects these requirements.

Table A-8. Estimated man-years of effort for Certification Implementation

	2001	2002	Total
Build I	1.0	1.0	2.0
Build IA	0.0	0.0	0.0

WBS 4.1.2, Program Control

No requirements were identified by the IPT.

WBS 4.1.3, Contract Management

No requirements were identified by the IPT.

A-1.2.2. WBS 4.2, Engineering

All activities associated with site surveys, design analysis, and studies. Table A-9 summarizes the year by year estimated manloading requirements for Build I and IA.

Table A-9 Estimated man-years required for Implementation Engineering Support

	1999	2000	2001	2002	2003	2004	2005	Total
Build I	2.1	2.1	2.1	2.1	2.1	1.0		11.5
Build IA				0.03	2.1	2.1	1.1	5.3

A-1.2.3. WBS 4.3, Environmental & Occupational Safety & Health Compliance

No requirements were identified by the IPT for either Build I or Build IA.

WBS 4.4, Site Selection and Acquisition

No requirements were identified by the IPT for either Build I or Build IA.

WBS 4.5, Construction

No requirements were identified by the IPT for either Build I or Build IA.

WBS 4.6, Installation and Checkout

All activities associated with the installation and checkout of system hardware, software, and equipment at the site in order to achieve operational status. The costs include labor (including overtime), travel, and contractor staffing.

Table A-10. Estimated man-years required for Installation & Checkout (I&CO)

	2001	2002	2003	2004	Total
Build I (FAA)	0.09	1.5	1.0		2.6
Build I (Cont.)	0.07	1.3	0.4		1.8
Build IA (FAA)		0.1	0.6	0.4	1.1
Build IA (Cont.)		0.4	1.0	0.4	1.8

WBS 4.7, Commissioning/Closeout

No requirements were envisioned by the IPT for post commissioning clean-up activities for either Build I or Build IA.

WBS 4.8, Telecommunications

No initial telecommunications implementation requirements were identified by the IPT for either Build I or Build IA.

WBS 4.9, Implementation Training

No requirements were identified by the IPT for either Build I or Build IA for initial, refresher, and attrition training for implementation personnel.

A-1.3. WBS 5.0, In-Service Management

A-1.3.1. WBS 5.1, Preventive Maintenance/Certification

All activities associated with the development and approval of procedures to support certification of the CPDLC system and communications service in accordance with FAA Order 6000.15, General Maintenance Handbook for Airway Facilities. These procedures will be documented and updated as part of the CPDLC technical data package and incorporated into the CPDLC training courseware material.

The IPT estimates the effort to perform these functions are 0.5 man-years in 2000 and 2001 for Build I, and 0.2 man-years in 2002 and 2003 for Build IA.

For each of the following WBS elements, the IPT has not identified any requirements that would be uniquely driven by the implementation of CPDLC Builds I and IA.

- WBS 5.2 Corrective Maintenance
- WBS 5.3 Modifications
- WBS 5.4 Maintenance Control
- WBS 5.6 Shift Augmentation
- WBS 5.7 Program Support
- WBS 5.7.1 Work Planning, Authorization and Management
- WBS 5.7.2 Program Control
- WBS 5.7.2 Program Control
- WBS 5.7.3 Contract Management

A-1.3.2. WBS 5.8, Logistics

WBS 5.8.1, Supply Support (F&E)

All the activities associated with the acquisition of In-Service Spares. Costs were estimated by AML-200. The assumption is DLAP is the only Line Replacement Unit (LRU).

WBS 5.8.2, Repair (F&E)

All activities associated with on-site maintenance services. On-site maintenance services will be performed at individual CPDLC facilities by contractor personnel throughout a two-year period of Interim Contractor Maintenance and Logistic Support (ICMLS), after which first level maintenance will transition to FAA Airway Facilities (AF) personnel. Initially, the contractor as a part of ICMLS will perform all second level maintenance. The FAALC will act as item managers for the CPDLC system and will manage the CPDLC system supply support system following the two-year ICMLS period.

Costs were estimated and provided by AML-200.

WBS 5.8.3, Support Equipment Maintenance (F&E)

All activities associated with the necessary support and maintenance of support and test equipment, including Automatic Test Equipment (ATE), to support the CPDLC system. This effort includes the tracking of assets and the logistical support of related equipment.

Costs were estimated and provided by AML-200.

WBS 5.8.4, Warranty Tracking (F&E)

All activities associated with bar-coding hardware inventory, including shipping containers, as well as any other special labeling that may be deemed necessary.

Costs estimated and provided by AML-200.

A-1.3.3. WBS 5.9, In-Service Training (F&E)

All activities associated with In-Service Training. Costs cover attrition and refresher training for personnel who directly operate, maintain, or provide support to the CPDLC system. Cost estimates were developed and provided by AMA-400 and ACT-350.

A-1.3.4. WBS 5.10, Second Level Engineering (F&E)

All activities associated with Second Level Engineering. The contractor provides Second Level Engineering support for the first two years, prior to transitioning to the cognizant FAA operational support organization. This includes software maintenance support. Cost estimates were developed and provided by AOS-300.

A-1.3.5. WBS 5.11, Infrastructure Support

5.11.1 Hazardous Materials Handling (F&E)

Required resources to ensure proper design considerations, procedures, processes and methods are addressed so that all CPDLC systems and subsystems, equipment and support items are preserved, packaged, labeled, handled and transported properly in accordance with ASTM-D3951, Standard Practice for Commercial Packaging. Costs were estimated and provided by AML-200.

WBS 5.11.2, Utilities, Building & Grounds Upkeep and Maintenance

The IPT identified no requirements under this WBS element required by the implementation of CPDLC Builds I and IA.

WBS 5.11.3, Telecommunications

All activities associated with maintaining, upgrading or modifying the operational and administrative communications services required for CPDLC Builds I and IA. Specifically, these are estimates of VDL Mode 2 Service Provider Contract Management costs developed and provided by the IPT and ACT-350.

WBS 5.11.4, Building and Infrastructure Improvements (F&E)

All activities associated with technical and management support to the CPDLC Maintenance Support Facilities (i.e., the FAA Logistics Center) including facilities improvements, environmental requirements, and space needs for support personnel at the sites. A modest cost to cover minor refurbishment to the depot to meet inventory control needs, such as a bonded storeroom, may also be incurred. Cost estimates developed and provided by AML-200.

WBS 5.11.5, Real Estate Acquisition and Management

No requirements identified by the IPT arising from the implementation of CPDLC Builds I and IA.

A-1.3.6. WBS 5.12, Flight Inspections and SIAP Development

No requirements identified by the IPT arising from the implementation of CPDLC Builds I and IA.

A-1.3.7. WBS 5.13, System Performance Assessment

All activities associated with the operational and engineering performance of the system from the cockpit perspective, including metrics development, data collection, and analysis. Estimate developed and provided by ACT-350.

A-1.3.8. WBS 5.14, System Operations

All non-maintenance activities associated with the direct operation and maintenance of the CPDLC system. The IPT identified no requirements unique to the implementation of Builds I and IA.

A-1.4. WBS 6.0, Disposition

This is an evolutionary program, one segment building atop the preceding one; disposition of CPDLC Build I and Build IA is meaningless. No costs were included in this analysis.

A-1.5. Operations Costs Separately Identified

WBS 5.8.1, Supply Support (OPS)

All activities associated with In-Service Spares. AML-200 provided the cost of In-Service Spares. Their estimate, as in the case for the F&E investment, assumes that the DLAP is the only LRU.

WBS 5.8.2, Repair (OPS)

All activities associated with system supply support. After the two-year period during which the contractor provides the on-site maintenance, first level maintenance will transition to FAA Airway Facilities (AF) personnel. The FAALC will act as item managers for the CPDLC system and will manage the CPDLC supply support system following the two-year ICMLS period. The cost estimates for this effort were developed and provided by AML-200.

WBS 5.8.3, Support Equipment Maintenance (OPS)

All activities associated with the necessary support and maintenance of support and test equipment, including automatic test equipment (ATE) required to support the CPDLC system. This area includes the tracking of assets and the logistical support of related equipment. Cost estimates were developed and provided by AML-200.

WBS 5.8.4, Warranty Tracking (OPS)

All activities associated with bar coding the hardware inventory, including shipping containers, as well as any other special labeling that may be deemed necessary. Cost estimates developed and provided by AML-200.

WBS 5.9, In-Service Training (OPS)

All activities associated with in-service training for personnel directly involved in the operation, maintenance, and support of CPDLC after the system is operational. AMA-400 developed and provided the cost estimates.

WBS 5.10, Second Level Engineering (OPS)

All activities associated with Second Level engineering. After the two-year period during which the contractor provides second level engineering support, AOS-300 identified the requirements and estimated costs associated with second level engineering support needed after transitioning to the responsible FAA operational support organization. This includes software maintenance support.

WBS 5.11.1, Hazardous Materials Handling

All activities associated with ensuring proper design considerations, procedures, processes and methods are addressed so that all CPDLC systems and subsystems, equipment and support items are preserved, packaged, labeled, handled and transported properly in accordance with ASTM-D3951, Standard Practice for Commercial Packaging. AML-200 identified this requirement and associated costs for required resources.

WBS 5.11.3, Telecommunications (OPS)

All activities associated with maintaining, upgrading or modifying the operational and administrative communications services required for CPDLC Builds I and IA. Specifically, these are estimates of VDL Mode 2 Service Provider Contract Management costs developed and provided by the IPT and ACT-350.

WBS 5.11.4, Building and Infrastructure Improvements (OPS)

Activities associated with providing the technical and management support to CPDLC Maintenance Support Facilities (I.e., the FAA Logistics Center) including facilities improvements, environmental requirements, and space needs for support personnel at the sites. A modest cost to cover minor refurbishment to the depot to meet inventory control needs, such as a bonded storeroom, may also be incurred. Cost estimates developed and provided by AML-200.

A-1.6. FAA Cost Risk Assessment

The primary risks associated with CPDLC Build I and IA program (from the perspective of the FAA investment) are 1) software development and 2) system end-to-end integration. Specific technical concerns are spelled out in the risk section of this report. The IAT, together with the IPT, assessed the major elements of program risk. Part of the assessment involved the identification of the scope of the risk and any risk mitigation strategies.

The IAT used an engineering assessment to determine the "best case " and "worst case" end estimates. These estimates were used as inputs to the risk model, called Crystal Ball, which then formed the basis for a Monte Carlo simulation resulting in the "high confidence" estimate. Tables A-1 through A-4 above show the source lines of code inputs used in the "Price S" software estimating model to determine the high, low, and most likely estimates based on the identified software risk areas. Table A-11 summarizes the other specific WBS elements where the identified risk could impact cost and/or schedule and the assessed impact.

Table A-11. Cost risk assessment

WBS	Description	Build I Risk Assessment		Build IA Risk Assessment	
		Low	High	Low	High
3.3.2	SW Development	See SLOC count	See SLOC count	See SLOC count	See SLOC count
3.3.3.1	SW Integration	$10.5M	$16.0M	$8.0M	$12.5M
3.5	Test and evaluation	ML - $1M	ML - $1.5M	ML - $1M	ML - $1.5M
3.2.7	Human Factors	N/A	N/A	ML - $1M	ML - $3.5M
3.6.7/ 3.7.8	All training WBSs	ML – 25%	ML + 25%	ML – 25%	ML + 25%

ML=most likely

A-2. Basis of Estimate and Assumptions for Service Provider costs

1. This estimate uses uplink and downlink message rates based on an analysis of a representative flight through en route airspace using data link. The assumption is that a representative flight would be about 1.5 hours and would pass through three ARTCCs covering about 12 sectors.
2. Message cost life-cycle is 10 years, but total life-cycle costs were calculated for 15 years (2000-2015).
3. The formula for computing charges to the FAA is as follows:

$$\frac{\$}{\text{KB}} * \frac{\text{messages}}{\text{hour}} * \frac{\text{KB}}{\text{message}} * \frac{\text{hours en route}}{\text{flight}} * \frac{\text{flights}}{\text{year}} * \frac{\text{Percent aircraft}}{\text{CPDLC equipped}} = \$/\text{year}$$

4. Estimate includes costs for both uplink and downlink messages.
5. Estimate includes costs for all message overhead including Transport and Application Layer protocols.

6. Estimate assumes Service Provider will charge a rate based on data link message traffic (in kilobits per year), and that the Service Provider Kilobit rate will decrease as message traffic increases.
7. Estimate assumes initial rate charged to the FAA will not exceed $0.20 per kilobit. In the worst case, the Service Provider will charge an initial rate that will not decrease over time.
8. Estimate assumes unsuccessful transmissions do not exceed 5% of all transmissions.
9. Average message sizes (uplink and downlink) are estimated for Build 1 and Build 1A. Table A-12 shows the most likely estimates of messages per flight (including Start messages – one per facility) and message sizes. The average NPDU message size (in bytes) is the total message size with protocol overhead included.

Table A-12. Average Messages per Flight and Message Sizes

Messages	Build I		Build IA	
	UP	DN	UP	DN
Messages Per Flight	53.9	48.3	94.1	91.3
Average Messages Per Sector	4.49	4.03	7.84	7.61
Average Message size (bytes)	16.29	8.14	15.50	8.21
Average TPDU Size (bytes)	26.24	18.20	25.04	17.77
Average NPDU Size (bytes)	34.75	27.23	31.63	24.43

10. This estimate assumes every message sent (including Logical Acknowledgements) requires a Transport Layer Acknowledgement.
11. Average message sizes (uplink and downlink) are estimated for the Build 1 and Build 1A Transport Layer Acknowledgements. Table A-13 shows average Transport Layer Acknowledgement message traffic and sizes (bytes). The average NPDU message size includes protocol overhead.

Table A-13. Average Transport Layer Acknowledgement Messages per Flight and Message Sizes

All T-ACK Messages	Build I		Build IA	
	UP	DN	UP	DN
Messages Per Flight	53.9	48.3	94.1	91.3
Average Messages Per Sector	4.49	4.03	7.84	7.61
Average Message size (bytes)	16.29	8.14	15.50	8.21
Average TPDU Size (bytes)	18.00	18.00	18.00	18.00
Average NPDU Size (bytes)	26.51	27.03	24.58	24.66

12. Initial contact with a facility (e.g., ARTCCs) requires a Start Message in uncompressed format.
13. This estimate assumes a proportion of operational message would require a Logical Acknowledgement. This assumption is based on two factors:

a) Airways Facilities (AAF) requires the logical acknowledgement to monitor the Service Provider contractual obligations.

b) Operational requirements might require a Logical Acknowledgement for every message.

14. This estimate assumes initial contact with a facility (e.g., ARTCCs) requires a Start Message in uncompressed format. This estimate assumes the first Technical Acknowledgement to the Start message is also uncompressed.
15. This estimate assumes that initial CPDLC VDL-2 equipage rates (prior to 2010) for airlines will be low and almost nil to very low for the regional air carriers and general aviation. These equipage rates can change as more information is received from the airlines.
16. This estimate assumes that initial CPDLC VDL-2 equipage rates (prior to 2010) for airlines and for the regional air carriers and general aviation will increase significantly after 2010. However, if NEXCOM Segments II and III are approved, it is estimated that low-end general aviation will equip with NEXCOM VDL-3 radios and will not equip with VDL-2 CPDLC radios.
17. Projections are based on the assumption that data link traffic will increase over the next 20 years as more users equip with CPDLC, and correspondingly cost per kilobit charged to the FAA will decrease.
18. Traffic and CPDLC data link forecasts for the military are not available and FAA costs for military CPDLC communications are not included in the estimates.
19. Message cost life-cycle is 10 years, but total life-cycle costs were calculated for 15 years (2000-2015).
20. Average Hours for a flight in en route airspace is derived from the latest *FAA Aviation Forecasts Fiscal Years 1998-2009 (FAA Forecasts)* report for air carriers, regional carriers, and general aviation. The FAA Aviation Forecasts identifies projected total average flight times by year. Twenty minutes is deducted from the yearly average flight time to account for time in en route airspace.
21. The number of flights per year is obtained from the *FAA Aviation Forecasts* for air carriers, regionals, and general aviation.

A-3. Basis of Estimate to Equip Aircraft with VHF Data Link Mode-2 (VDL-2) Controller-Pilot Data Link Communications (CPDLC) Airborne Avionics for CPDLC Build I and IA

What follows below represents the FAA's understanding of informal conversations and discussions held with several representative user interests. The FAA invites continued input from the user community to help make the FAA estimates of user CPDLC equipage costs as accurate as possible.

This cost estimate addresses the costs for the U.S. domestic aviation user community to equip aircraft with VHF Data Link Mode-2 (VDL-2) CPDLC avionics for CPDLC Build I/IA.

- Costs are estimated to retrofit existing fleet aircraft and to equip new aircraft with VDL-2 and CPDLC.
- Life cycle of avionics is 15 years.
- Costs are estimated to equip new VDL 2-capable aircraft for VDL-2 with CPDLC for each of five basic user categories:
  - Air carrier
  - Regional/commuter
  - Corporate general aviation

- Low-end general aviation
- Military

- It is estimated that approximately 81.7% of the current air carrier fleet and 50% of the regional/commuter/corporate general aviation fleet is equipped with ACARS.
- This estimate assumes that, for CPDLC Build I/IA, obtaining VDL-2/CPDLC capability with new aircraft is a more cost effective way for the aviation industry to transition a fleet to CPDLC capability than to upgrade existing aircraft.
- Because relocating the current ACARS Control Display Unit (CDU) in an aircraft can involve considerable expense to the user community, it is estimated that users will choose to forward-fit new aircraft with VDL-2/CPDLC capability instead. Therefore, costs are not estimated for relocation of aircraft cockpit displays. It is assumed that new aircraft designs would include the necessary arrangement of displays to meet CPDLC requirements.
- Retrofitting current fleet aircraft may incur additional costs to equip for CPDLC, such as relocation or replacement of the existing Control Display Unit. This estimate assumes most air carriers and regional/commuters will order new aircraft with at least VDL-2/AOC capability, that can be upgraded to CPDLC capability, and will retrofit existing fleet aircraft for CPDLC only if absolutely necessary.
- It is estimated that most new domestic aircraft delivered after the year 2005 will be equipped with at least VDL-2/AOC capability and can be upgraded to VDL-2/CPDLC capability. The year 2005 allows time for aircraft manufacturers to incorporate VDL-2 functionality into future aircraft models.
- It is estimated that future aircraft designs will include CPDLC functionality (e.g., placing the ACARS CDU in the pilot line-of-sight to facilitate observation of Air Traffic messages). Therefore, costs are not included in the avionics estimates for relocating cockpit components (e.g., ACARS CDU) in current fleet aircraft to satisfy CPDLC requirements. Only the communications hardware and software costs needed to equip VDL-2 aircraft with CPDLC capability are estimated.
- An aircraft with VDL-2/AOC capability requires a VDL 2-capable radio, a Level D (or Level E) communication management unit (CMU), and a CDU to display messages. Hardware costs[1] to equip a new aircraft (or an existing non-ACARS aircraft) with VDL-2/AOC capability are included for the following components:
  - Air carrier
  - 1 VDL-2 digital radios
    - 1 communications management unit
    - 1 cockpit display unit
  - Regional/commuter/corporate general aviation
    - 2 VDL-2 digital radios
    - 2 communication management unit
    - 1 CDU
  - Low-end general aviation
    - 1 VDL-2 digital radio
    - 1 cockpit display unit

[1] Costs are contained in “Official Use Only” version of the Investment Analysis Report

- Military
  - 1 VHF digital radio(s) with VDL-2
  - 1 set control heads
- Estimated software costs to upgrade existing digital aircraft that are already ACARS-equipped to VDL-2/AOC are included for the following components:
  - Air carrier
    - 1 Software Upgrade of ACARS radios
    - 1 Software Upgrade of CMU
  - Regional/commuter/corporate general aviation
    - 1 Software Upgrade of ACARS radios
    - 1 Software Upgrade of CMU
- The basic requirements to provide VDL-2/AOC equipped aircraft with Build I/IA CPDLC capability is to upgrade the current CMU to a Level C CMU, and to ensure that the ACARS CDU is in the pilot's line of sight. Because relocating the current ACARS CDU in an aircraft can involve considerable expense to the user community, it is estimated that users will choose to forward-fit new aircraft with VDL-2/CPDLC capability instead. Therefore, costs are not estimated for relocation of aircraft cockpit displays. It is assumed that new aircraft designs would include the necessary arrangement of displays to meet CPDLC requirements.

  Only the communications hardware and software costs needed to equip VDL-2 aircraft with CPDLC capability are estimated. Communications components included:
  - Air carrier - 1 Level C CMU Upgrade
  - Regional/commuter/corporate general aviation - 1 Level C CMU Upgrade
  - Low-end general aviation - 1 Level C CMU Upgrade
  - Military - 1 Level C CMU Upgrade
- In addition to the hardware costs considered above, the following cost estimates were included:
  - Software upgrade to CMU from ACARS capability to VDL-2 capability
  - Digital radio wires ($40 per wire)
  - Installation ($65 per hour for all aircraft except military; $85 per hour for military aircraft)
  - STC VDL-2/CPDLC certification costs for air carrier and regional/commuter aircraft
    - digital radio ($20,000)
    - ACARS Control Display Unit ($30,000)
    - CMU ($25,000)
  - Hardware spares (15% additional hardware for air carrier and regional/commuter aircraft; 20% additional hardware for military aircraft)
- New Aircraft Costs: The basic methodology for deriving estimated cost to equip an aircraft with VDL-2 and CPDLC capabilities, for each user category, for each year was to multiply the following components:

  (equipage cost per aircraft) x (total number of aircraft to be equipped) = costs

Hardware and software equipage costs are estimated to be the same for both new aircraft and retrofit aircraft. Radios and CMUs are buyer-supplied items. The ACARS Control Display Unit is a Seller-supplied item (aircraft manufacturer).

Installation costs are estimated to be 10% less for new aircraft compared with retrofit aircraft, due to economies of production.

The total number of aircraft to be equipped for a specific year is calculated by multiplying the increase in projected equipage with VDL-2/CPDLC, by the fleet quantity for the specific year.

In the case of air carrier and regional/commuter aircraft, costs are added for certification.

- Spares cost on a per aircraft basis by applicable user category is estimated as 15 % of the basic hardware and software costs for air carriers and regional/commuter aircraft.
- Costs are not included for pilot training and for modifications to airline flight simulators. These costs are considered as Build 2 costs.
- It is assumed that retrofits and software upgrades for commercial aircraft can be accomplished within the regular maintenance cycle and therefore no out-of-service costs are included.
- VDL-2/CPDLC certification costs for STC are calculated for all air carrier and regional/commuter aircraft types that are to be certified. Total certification costs are estimated by multiplying the estimated certification cost per unit of equipment times the estimated number of times the equipment would need to be certified. An aircraft type can be specific to a vendor. For example a Boeing 747/400 can be procured by two different airlines and have slight variations. Each airline's individual configuration is considered a different aircraft type requiring certification.

Total certification costs are then allocated over the first six years of the equipage period for each applicable user category.

Relying on conversations with industry and FAA representatives, yearly certification costs are split between VDL-2/AOC and VDL-2/CPDLC as follows:

- 60% of the yearly certification costs are attributed to VDL-2/AOC (Costs include the basic certification cost of the system)
- 40% of the yearly certification costs are attributed to VDL-2/CPDLC (Costs include the basic certification costs of the message set)

Total Build I/IA certification costs estimated by user category are contained in Tables A-14 and A-15.

Table A-14. Airline Fleet New Aircraft Certification Costs

Component	Certification Cost	Number of Aircraft Types	Percent CPDLC Equipped	Total
Digital radio	$20,000	130 aircraft	60%	$1,560,000
Control Display Unit	$30,000	130 aircraft	60%	$2,340,000
CMU	$25,000	130 aircraft	60%	$1,950,000
		Total Airline Certification Costs		**$5,850,000**

Table A-15. Regional Fleet New Aircraft Certification Costs

Component	Certification Cost	Number of Aircraft Types	Percent CPDLC Equipped	Total
Digital radio	$20,000	140 aircraft	50%	$1,400,000
Control Display Unit	$30,000	140 aircraft	50%	$2,100,000
CMU	$25,000	140 aircraft	50%	$1,750,000
	Total Regional/Commuter Certification Costs			**$5,250,000**

VDL-2 (AOC only) most likely equipage cost per new aircraft (including installation and discounts but excluding certification and spares) are estimated by user category and included in the total industry avionics cost estimate to transition aircraft to VDL-2/AOC capability.

The estimated VDL-2 equipage cost per new aircraft (excluding spares) by user category are in the “Official Use Only” version of the Investment Analysis Report.

Marginal CPDLC most likely equipage cost per new aircraft (including installation and discounts but excluding certification and spares) were also estimated by user category and included in the total industry avionics cost estimate to transition aircraft to VDL-2/CPDLC capability from VDL-2/AOC.

The estimated marginal CPDLC equipage cost in addition to VDL-2 costs per aircraft are in the “Official Use Only” version of the Investment Analysis Report.

Projected growth in the air carrier fleet and in aviation traffic statistics is derived from the FAA Aviation Forecasts Fiscal Years 1998-2009 and FAA Long-Range Forecast 2007-2020.

The data sources used to derive the cost estimates are in Table A-16.

Table A-16. Data Sources for Costs

Component	Data Source
Commercial and general aviation fleet	FAA Aviation Forecasts Fiscal Years 1998 - 2009
Percentage of general aviation fleet that is corporate and percentage that is radio equipped	General Aviation and Air Taxi Activity and Avionics Survey, Calendar Year 1995
Military fleet	Department of the Air Force
Avionics cost	Avionics manufacturers, Department of the Air Force
Installation cost	Avionics manufacturers, contract repair companies, and Department of the Air Force
Certification cost	Airlines, contract repair companies
Out-of-service cost	Estimated based on contract information from airlines repair companies and factors in FAA Aviation Forecasts Fiscal Years 1997 - 2008

This estimate assumes that initial CPDLC VDL-2 equipage rate (prior to 2010) for airlines and for the regional air carriers and general aviation will increase significantly after 2010. However, if NEXCOM Segments II and III are approved, it is estimated that low-end general aviation will equip with NEXCOM VDL-3 radios and will not equip with VDL-2 CPDLC radios.

Build I/IA CPDLC equipage is assumed to begin in 2000. CPDLC equipage rates were estimated from interviews with industry representatives including airlines, and aircraft and radio manufacturers. Build I/IA CPDLC equipage rates were applied to the total number of aircraft in each category in 2000. The equipage rates by user category were as illustrated in Table A-17.

Table A-17. Data Link VDL-2/CPDLC Avionics Equipage Assumptions

	Percentage of Total Equipage					
Calendar Year	Air Carrier	Regional/ Commuter	Corporate General Aviation	Other Radio Equipped GA	Overall General Aviation	Military
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	1	0	0	0	0	0
2003	1	0	0	0	0	0
2004	1	0	0	0	0	0
2005	2	0	0	0	0	0
2006	5	0	0	0	0	1
2007	12	1	2	0	0	2
2008	20	1	3	0	0	3
2009	25	2	4	0	0	4
2010	29	3	9	1	1	5
2011	32	6	20	2	3	6
2012	36	13	29	3	4	7
2013	39	19	32	4	5	8
2014	43	21	35	5	6	9
2015	46	24	39	6	7	10
2016	50	26	42	7	8	10
2017	52	28	45	8	9	10
2018	53	30	47	9	10	10
2019	53	31	48	10	11	10
2020	53	32	48	10	11	10

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Appendix B: Preliminary Operational Safety Analysis Report

B-1. Introduction

In early August a decision was made to conduct a preliminary operational safety analysis (OSA) of CPDLC Build IA. An ad hoc group was assembled and tasked with conducting the effort within a two-week time period.

It was agreed that the basic principles described in RTCA SC-189/EUROCAE WG-53 Paper P/SG2/10, *Guidance for Conducting an Operational Safety Analysis*, and RTCA SC-189/Eurocae WG-53 P/SG2/2, *Characteristics of the CNS/ATM Operational Environment for Air Traffic Services (ATS) that Use Data Communications*, would be adhered to for the OSA portion of the analysis.

B-2. System Description:

CPDLC Build IA is a system providing data communication capability between pilots and controllers using a series of message sets designed to assist in airspace management. The message sets are a limited grouping of standardized communications allowing controllers and pilots to communicate using an alternative to voice.

Build IA is designed to be used in Positive Control Airspace (PCA) only. The message groups are designed to allow retention of current safety characteristics of the airspace. Messages will be transmitted and received through an Uplink and Downlink process between the Data System Display (DSR) for controllers and the Cockpit Display Unit (CDU) for pilots.

Build IA will be introduced as a supplemental communication capability for controllers and pilots without any reduction in the voice communication available in the current system.

B-3. System Operations:

Data link equipped aircraft operating in PCA routinely communicate with air traffic control facilities to receive information and guidance to preserve the safety of their operations. Traditionally this communication is transmitted and received via voice transmissions through an extensive ground VHF system and transmitters and receivers in the aircraft.

The messages and procedures associated with these messages are principally designed to ensure separation between aircraft operating at approximately 500 knots in PCA. The messages are generated by air traffic controllers who monitor the progress and positions of the various aircraft using a combination of computer/radar generated display.

This monitoring service will be modified slightly by the introduction of CPDLC by the availability of additional data on the controller's display. The cockpit environment will be modified by the addition of a data display for CPDLC messages.

B-4. System Safety Engineering:

System safety is an engineering process for the identification and management of safety related risks**.** This process involves various applications and techniques that have evolved over the years. Experience in identifying and controlling hazards has resulted in a recognized discipline with accepted procedures for performing various stages of risk assessment.

Appendix B: Preliminary Operational Safety Analysis Report

The process applied to CPDLC IA in this exercise can be described more accurately as a hazard analysis rather than an Operational Safety Assessment (OSA). The rationale for using this process was based on established safety engineering practice. An OSA, as described in the related RTCA documents, is essentially a high level overview of the entire world-wide aerospace system, including various components such as communications, navigation, surveillance and air traffic management.

By selecting CPDLC as the sole subject of this evaluation, it was determined that a hazard analysis had to be conducted to identify any undiscovered risks inherent in the CPDLC architecture and/or mission needs statement which, if not addressed, could result in significant cost increases or schedule delays prior to the JRC scheduled in October.

It is recognized that an OSA must be conducted on the end-to-end system to determine build requirements and mitigation strategies. This OSA should be initiated immediately following the final modifications or amendments to this hazard analysis in order to remain within the development schedule and budget perimeters for CPDLC deployment.

B-5. Committee

The committee conducting the hazard analysis relied on subject matter experts (SME) from various organizations associated with the development of CPDLC. These SMEs represented the Federal Aviation Administration (FAA) Office of Aircraft Certification (AIR), System Safety Office (ASY), Air Traffic Operations (ATO), and the Air Traffic Systems Requirements Office (ARS); the Aeronautical Data Link Office of Crown Communications, Inc., the CAASD of the Mitre Corporation, and ARINC.

B-6. Assumptions

This analysis is not all-inclusive. There may be unknown risks. This is a worst case analysis. Additional mitigations and controls may be identified as a result of future analysis efforts.

CPDLC Build I/IA is not intended to be used in the Terminal Area. Voice communications and related systems shall remain intact and will be used as the primary means of airspace management. Some messages will be used for airspace management, i.e., from controller to air crew.

Separation standards will not change because of the introduction of CPDLC. In the aircraft, the CMU is the end of the system, not the FMS.

B-7. Recommendations

The committee identified 31 hazard scenarios along with associated hazard controls and mitigations. The committee recommends:

- These controls and mitigation should be included in the system requirements.
- The hazard scenarios will be considered unresolved until such time that the mitigations and controls have been implemented formally.
- At that time the identified risks will be adequately eliminated or controlled to an acceptable level.
- Any changes in the CPDLC IA design should be evaluated from a system safety view.

To complete the risk assessment process, likelihood estimates must be determined. These estimates will be a result of future system and subsystem hazard analysis. Appropriate system and subsystem hazard analysis is required for the CPDLC system.

The risks associated with changes in the NAS should be evaluated for system safety.

The worksheets on the next four pages will help with this procedure.

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Preliminary Operational Safety Analysis

Worksheet 1

Hazard Description:	Possible Effect:	Phase	Recommendations for Precautions, Controls, and Mitigations
(1) Loss of airborne VHF Comm, data and voice, due to weather 3 | 3	Possible loss of CPDLC to affected aircraft	En Route Cruise	(a) Contingency procedures in place, i.e.; NORDO procedures
(2) Loss of ground VHF Comm, data and voice, due to weather 3 | 3	Possible loss of CPDLC at affected ground station	En Route Cruise	(a) Possible backup communications for ground stations
(3) Possible loss of power effecting CPDLC, due to failure 3 | 5	Possible loss of CPDLC at affected ground station	En Route Cruise	(a) Design for redundant power for CPDLC (b) Switch to existing ATC procedures, i.e., voice transfer of communications
(4) Incorrect message sent, due to human error 1 | 3	Possible incorrect clearance to air crew	En Route Cruise	(a) Design CPDLC with appropriate CHI (b) Consider command verification action in design (c) Deviation will be indicated on radar (d) ATC voice intervention
(5) Incorrect message sent, due to failure and/or software malfunction 1 | 3	Possible incorrect clearance to air crew	En Route Cruise	(a) Design CPDLC to assure that failures/malfunctions are automatically detected. (b) Consider command verification action in design (c) Deviation will be indicated on radar (d) Switch to existing ATC procedures, i.e., voice transfer of communications
(6) Incorrect message sent, due to security intrusion 1 | 1	Possible incorrect clearance to air crew	En Route Cruise	(a) Design CPDLC to minimize the risk of security intrusion, including detectability, auditing, and software protection. (b) Consider command verification action in design (c) Deviation will be indicated on radar (d) Switch to existing ATC procedures, i.e., voice transfer of communications (e) Provide message authority verification in design
(7) Message sent to wrong aircraft, due to error 1 | 3	Possible incorrect clearance or instruction to aircraft	En Route Cruise	(a) Deviation will be indicated on radar (b) Design the CPDLC CHI to minimize the potential for human error (c) Include command verification action in design (d) Switch to existing ATC procedures, i.e., voice transfer of communications (e) Provide message authority verification in design
(8) Message sent to wrong aircraft, due to failure and/or malfunction 1 | 3	Possible incorrect clearance or instruction to aircraft	En Route Cruise	(a) Design CPDLC to assure that failures/malfunctions are automatically detected. (b) Consider command verification action in design (c) Deviation will be indicated on radar (d) Switch to existing ATC procedures, i.e., voice transfer of communications (e) Provide message authority verification in design
(9) No valid response received, due to failure/software malfunction 1 | 4	Loss of communications	En Route Cruise	(a) Design CPDLC to assure that failures/malfunctions are automatically detected. (b) Consider command verification action in design (c) Deviation will be indicated on radar (d) Switch to existing ATC procedures, i.e., voice transfer of communications

Comments:
NORDO, or NO RaDiO, lost communications procedures for air crew are detailed in the *Aeronautical Information Manual*, CFR14 Part 91, on approach plates, and other regulatory documents.

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Preliminary Operational Safety Analysis

Worksheet 2

Hazard Description:	***Possible Effect:***	***Phase***	***Recommendations for Precautions, Controls, and Mitigations***	***Comments:***
(10) Corrupted message indicated on DSR due to failure/software malfunction 1 | 4	Incorrect message displayed to controller	En Route Cruise	(a) Design CPDLC to assure that failures/malfunctions are automatically detected (b) System shall be designed to indicate failures (c) Failure indication shall be designed to conform to HF Design Guide CT-96/1 , i.e., audible alarms (d) Switch to existing ATC procedures, i.e., voice transfer of communications	
(11) Corrupted message indicated on CDU due to failure/software malfunction 3 | 4	Incorrect message displayed to air crew	En Route Cruise	(a) Design CPDLC to assure that failures/malfunctions are automatically detected (b) System shall be designed to indicate failures (c) Failure indication shall be designed to conform to HF Design Guide CT-96/1 , i.e., audible alarms (d) Switch to existing ATC and/or company procedures, i.e., voice transfer of communications	
(12) Corrupted/erroneous altitude setting message due to malfunction 1 | 4	Incorrect message displayed to air crew resulting in an erroneous but credible altitude setting	En Route Cruise	(a) Design CPDLC to assure that malfunctions are automatically detected (b) When air crew WILCOs with incorrect altitude, system alerts controller to the mismatch of the altitude (c) Failure indication shall be designed to conform to HF Design Guide CT-96/1 , i.e., audible/visible alarms (d) Switch to existing ATC procedures, i.e., voice transfer of communications	
(13) Possible decrease in situtional awareness due to loss of "party line" 1 | 4	Air crew loss of situational awareness	En Route Cruise	(a) Human Factors shall evaluate the possible loss of situational awareness due to loss of party line (b) Design and equip CPDLC with possible complementary equipment which will mitigate the loss of situational awareness or enhance situational awareness (c) Establish human factors procedures to reduce the possibility of loss of situational awareness	
(14) Possible saturation of entire CPDLC system and/or a component, resulting in the loss of communication or channel 1 | 2	Loss of communication, one or more ARTCC HOSTs crashes	En Route Cruise	(a) Design CPDLC system so that in the event of overloads or other malfunctions, the system shall be isolated to eliminate the possibility of loss of the HOST or other service degradation (b) Switch to existing ATC procedures, i.e., voice transfer of communications	
(15) Undetected loss of backup voice radio capability due to failure and/or error. 1 | 4	Inability to send or receive emergency or urgent transmissions	En Route Cruise	(a) CPDLC shall require a positive establishment of both voice *and* data contact in any transfer of communications and/or responsibility (b) Switch to existing ATC procedures, i.e., return to previous frequency	CPDLC works independently of voice com; the controller-initiated data link channel transfer of communications does *not* change the voice comm channel in the aircraft; HOST is programmed to change the data channel automatically if the controller doesn't manually handoff.
(16) Erroneous free text message due to human error 1 | 4	Possible incorrect instruction or other message received by air crew	En Route Cruise	(a) Design the CPDLC CHI to minimize the potential for human error	
(17) Intelligent corruption caused by hardware, software, or firmware malfunction results in erroneous message due to lack of end to end integrity checks. 1 | 4	Possible incorrect instruction or other message received by air crew or controller	All	(a) Design the CPDLC to include end to end integrity checks. (b) Design CPDLC to assure that malfunctions are automatically detected (c) System shall be designed to indicate failures (d) Failure indication shall be designed to conform to HF Design Guide CT-96/1, i.e., audible/visible alarms	ATN end to end check sum is not all inclusive. Right now, checks are between CMU and DLAP. Need to be between DSR and CDU.

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Preliminary Operational Safety Analysis

Worksheet 3

Hazard Description:	*Possible Effect:*	*Phase*	*Recommendations for Precautions, Controls, and Mitigations*	*Comments:*
(18) Intelligent corruption caused by hardware, software, or firmware malfunction results in erroneous message due to undetected secondary failure of end to end integrity checks. 1 | 3	Possible incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) Design CPDLC end-to-end integrity check system to meet availability and reliability requirements TBD	
(19) Intelligent corruption caused by commercial, off-the-shelf (COTS), or non-developmental items (NDI) malfunction results in erroneous message. 1 | 3	Possible incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) Design CPDLC system architecture to ensure failure isolation of COTS and NDI hardware, firmware, and software (b) Design CPDLC system architecture to ensure that COTS and NDI hardware, firmware, and software fail safe (c) Provide COTS and NDI hardware, firmware, and software discriminators TBD	
(20) Intentional disregard of specific message due to frequent malfunctions of system. 1 | 4	Possible disregard of instruction or other message received by air crew or controller	En Route Cruise	(a) Design CPDLC end-to-end integrity check system to meet availability and reliability requirements TBD (b) Human Factors shall evaluate the possibility of minimizing intentional disregard of specific messages, i.e., intermittent alert switch (c) Switch to existing ATC procedures, i.e., voice transfer of communications	
(21) Intelligent corruption caused by hardware, software, or firmware malfunction results in erroneous message due to electromagnetic environmental hazards. 1 | 4	Possible incorrect instruction or other message received by air crew or controller	All	(a) Design the CPDLC to be hardened against electromagnetic interference to the standards in FAA G-2100-F, MIL-STD-461D, MIL-STD-462D, and FCC regulations (b) Design CPDLC to assure that malfunctions are automatically detected (c) System shall be designed to indicate failures (d) Failure indication shall be designed to conform to HF Design Guide CT-96/1, i.e., audible/visible alarms	(a) FAA G-2100-F, *Electronic Equipment, General Requirements* (b) MIL-STD-461D, *Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility* (c) MIL-STD-462D, *Measurement of Electromagnetic Interference Characteristics*
(22) Late message timing/sequencing leads to confusion, erroneous actions. 1 | 3	Possible incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) Design CPDLC system to assure that message order is consistent or there will be an error message sent (b) Design CPDLC system with end-to-end timing requirements for verification (c) Design CPDLC system with requirements for message time-out optimization	
(23) Inappropriate response to specific message due to less than adequate acclimation, i.e., aircraft mix 1 | 4	Possible disregard of instruction or other message received by air crew or controller	En Route Cruise	(a) Provide appropriate training and orientation to air crew and controllers (b) CPDLC system shall be designed to conform to HF Design Guide CT-96/1 , i.e., ease of use, appropriate line of sight, etc. (c) Provide appropriate procedures to include contingency responses, i.e., placard the system if it becomes inoperable and go to voice	
(24) Conflicting communication between data link & voice 1 | 3	Incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) Identify protocols to resolve conflicts and confusion between voice and data communications (b) Protocols for the CPDLC system shall be designed to conform to HF Design Guide CT-96/1, i.e., voice has priority	
(25) Inappropriate mixture of voice & digital comm provides confusion 1 | 3	Incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) CPDLC system shall be designed to conform to HF Design Guide CT-96/1, i.e., incorporate procedures to restart data communications	
(26) There is no "Disregard" message in CPDLC. ? | ?	Incorrect instruction or other message received by air crew or controller	En Route Cruise	(a) CPDLC shall provide appropriate procedures to include contingency responses, i.e., go to voice (b) CPDLC systems shall be designed to provide a specific "Disregard" message	
(27) RF Saturation results in loss of CPDLC communication 1 | 2	Loss of CPDLC communications at all saturated stations	All	(a) Switch to existing ATC procedures, i.e., voice transfer of communications	

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Worksheet 4

Hazard Description:		***Possible Effect:***	***Phase***	***Recommendations for Precautions, Controls, and Mitigations***	***Comments:***
(28) Digital "stuck mike," i.e, continuous transmission	1 | 4	Possible loss of CPDLC communications	En Route Cruise	(a) Switch to existing ATC procedures, i.e., voice transfer of communications (b) Design system to minimize the possibility of a "stuck mike" failure	
(29) Possible decrease in situtional awareness due to field of vision considerations	1 | 4	Air crew loss of situational awareness due to "head-down" time	En Route Cruise	(a) Human Factors shall evaluate the possible loss of situational awareness due to field of vision considerations (b) Design and equip CPDLC with possible complementary equipment which will mitigate the loss of situational awareness or enhance situational awareness (c) Establish human factors procedures to reduce the possibility of loss of situational awareness	
(30) Physical hazards associated with CPDLC hardware	1 | 1	Possible injury to personnel and/or damage to hardware/aircraft	All	(a) Design CPDLC to the standards in RTCA DO-160C, FAA 2100F, and FCC regulations (b) CPDLC system shall be designed to conform to HF Design Guide CT-96/1	(a) RTCA DO-160D *Environmental Conditions and Test procedures for Airborne Equipment* (b) FAA G-2100-F, *Electronic Equipment, General Requirements* (c) FCC regulations
(31) Computer/human interface sequence incompatibility	3 | 3	Possible loss of situational awareness through information overload	En Route Cruise	(a) CPDLC system shall be designed to conform to HF Design Guide CT-96/1	

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